NUCLEAR ENGINEERING VOL. 2 NO. 13 APRIL, 1957

EDITORIAL

Power Programme Expansion

THE awaited revision of the 1955 White Paper was announced simultaneously in the House of Commons and the House of Lords on March 5. The new programme contains few surprises and confirms expectations that nuclear capacity scheduled for installation by 1965 amounts to between 5,000 and 6,000 MW. The plan can at this stage still only be regarded as an interim measure, and periodic revision must be made. Nineteen stations are at present envisaged, each with an available capacity comparable with those now under construction for the C.E.A. What remains to be seen is whether the number of stations or the total output can be regarded as fixed. With the fossil fuel situation now obtaining, and with the definite prospects that both coal and oil will rise steadily in cost and become increasingly difficult to get, Government policy must dictate the maximum investment in nuclear power that is compatible with raw material (particularly steel) availability. The sooner nuclear sources can replace conventional sources of energy for generating electricity, the sooner will Britain's industry be able to shake itself free from fuel inflation and political uncertainties.

The heat output from a Calder Hall reactor is 185 MW, whereas the design output of its C.E.A. counterpart is already more than three times this figure. This by no means represents the ultimate in the development of the type. Even without fundamental changes in rating, such as would accompany the use of beryllium as a canning material, heat output from a single reactor will steadily increase. This will involve larger pressure vessels, with the incorporation of more uranium and graphite and larger biological shields, but the quantities of material used will not be proportional to heat. Increased ratings will result in greater "specific" ratings and, as an obvious corollary, a decrease in the capital cost per kW. We can expect to see reactor heat ratings in the not very distant future rise to 650 MW, to 800 MW and then 1,000 MW, with two-reactor power stations offering an available capacity of 400 MW, 500 MW and 650 MW. This will take time, of course, but it seems reasonable to suggest that designs tendered in 1960 for stations to be completed in 1965 will include outputs in the region of 500 MW. The average size of station to be completed in the next ten years may therefore amount to 400 MW, and the total capacity from 19 stations 7,600 MW. Certainly, then, the lower figure quoted in the recent announcement—5,000 MW—must be considered a very conservative minimum and even the upper figure of 6,000 MW is likely to fall short of reality by a significant margin.

The Government has been at pains to make known its awareness of the problems of siting the new stations. From an amenity point of view, the position is simply that we need new power stations of some sort and they must be put somewhere. From the architect's impressions that have appeared in these pages and the national Press of the three stations under contract, few would argue that the nuclear power stations are less susceptible to a sympathetic treatment than even a "smokeless" conventional station. We would even suggest that the appearance of certain parts of the country-side would be improved by such installations. This is not the main issue, however. It is desirable that sites should be coastal and reasonably remote, and the number of sites that fulfil these qualifications are limited. The first consideration will be largely a function of steam conditions, and these will steadily approach those found in conventional stations. The second is not so straightforward. Present-day philosophy calls for stations to be erected in sparsely-populated areas, so that personal attention can be paid to local inhabitants and decontamination is reduced to a minimum should the need arise. Transmission problems can become acute if this attitude is maintained too long, and by 1965 we must expect reactors to be constructed nearer the load centres. The grouping of stations together will also tend to increase

transmission costs, unless groups are sited near concentrated industrial regions.

The statements on exports made at the time of the Minister of Power's announcement are encouraging, as they show that the Government is appreciative not only of the fuel problems in this country but also of the potential market that exists abroad for the export of relatively large base load stations. Implicit also is the assurance that supplies of essential materials will be sufficient to meet demands and that all expected export contracts can be fulfilled. The demand in terms of materials and man-power will depend on the purchasing country, but as more inquiries are received by the contracting groups the more clearly can it be seen that the major business is going to be in design rights. On the other hand, some of the specialized equipment will not be available overseas, and for many years it is likely that some components will only be available from this country. This picture can be altered if overseas countries decide to standardize their reactor programmes on the Calder Hall type, but the present tendency is for the highly industrialized countries to consider a number of types and some time must elapse before a clear pattern in any one country is established. The challenge, therefore, to component manufacturers is considerable and the opportunity is there for the establishing of a commanding lead in their particular technology.

But to return to the programme: some concern has been expressed at the prospect of the country wedding itself at so early a stage to such a large gas-cooled graphite-moderated programme. It would certainly be a bold man who would deny the possibility of another system when fully developed being a more economic proposition than the Calder type. We suggest, however, that it would be a very much bolder man who forecast that any of the stage 3 types would ultimately cost out dramatically cheaper than the type that now forms the basis for our power expansion. It is availability that will count most in the future, rather than the second decimal point in the cost per kWh. Until such time that a definite reactor type has advanced to the point when industrial designs can be confidently begun, we should have no hesitation in investing in nuclear power stations up to the maximum rate of increase required, provided only that a crippling load is not placed on other engineering enterprises.

Nuclear Engineering Scholarship

Nuclear Engineering invites applications for a Post-graduate Scholarship to be awarded for the year 1957-58.

The objects of the Scholarship are to enable the holder:

(a) To pursue studies at post-graduate level directed towards some aspect of nuclear engineering; and

(b) To pursue an approved programme of research in some aspect of nuclear engineering.

The amount of the award will depend upon the circumstances of the successful candidate's case, but will usually be £350 per annum and will in no case exceed £400 per annum. The amount and duration will be assessed by the Selection Committee.

The normal duration of the Scholarship will be one year, or such longer or shorter period as may be approved.

Scholarships will be tenable at universities, technical colleges and other educational establishments (in the United Kingdom) approved by the Selection Committee.

GENERAL CONDITIONS

1. The candidate must be a British subject normally resident in the United Kingdom, with a university degree or its equivalent in engineering, physics, chemistry or metallurgy.
2. A candidate is required to submit a programme of work which he would undertake during the tenure of the Scholarship, together with an estimate of the cost of carrying it out, including personal expenses. Any other awards, allowances, etc., to the candidate, which would be concurrent with the *Nuclear Engineering* Scholarship, should be described.
3. The candidate is to furnish names and addresses of two referees who will be asked to advise the Selection Committee on the qualities of the candidate.
4. The award will be made at the absolute discretion of a Selection Committee.
5. The successful candidate shall devote his whole time to the programme of work proposed by him, with such alterations as the Selection Committee may, with the candidate's agreement, approve at the time of the award.
6. At the completion of a Scholarship, a report is to be submitted, but interim reports on the work may be required from time to time.
7. Application forms can be obtained from the Editor, *Nuclear Engineering*; when completed they should be returned to arrive not later than June 30, 1957.
8. Applications received will be considered by the Selection Committee, and a short list (if necessary) prepared of candidates required for interview by the Committee in London. Approved travelling and subsistence expenses will be defrayed.
9. The Selection Committee reserves the right to elect such candidates as it may approve and the grounds on which particular candidates have been elected or rejected need not be given.
10. In the case of an award for one year, payments will be made as follows:
    October 1—one-half of award;
    January 1—one-quarter;
    April 1—one-quarter.
11. The Selection Committee may terminate a Scholarship at any time if it is not satisfied with the progress or conduct of the student.
12. Candidates should furnish evidence when required to the Committee that their programmes of work have the approval of the head of the institution or department in which they propose to work.

Comments on the News

U.K.—U.S. EXCHANGE

Criticisms have been voiced in the U.S. on the tardy manner in which Britain is releasing information on the Calder Hall project, whereas full details on the *Nautilus* have already been passed over. Such comments could scarcely be farther from the truth. At the time of writing, quite apart from the comprehensive information which was released about the Calder Hall project in October and November (*Nuclear Engineering*, October; B.N.E.C. Symposium, November) which gave a fuller account of a nuclear power station than had ever been done before, further detailed information has already been transmitted to the U.S. on the Calder Hall project—in fact, as much as is considered requisite under the tripartite agreement. Furthermore, preparations are under way for the collation of similar information included in the commercial designs, so that this also can be transmitted to the U.S. In addition, negotiations are in hand for the exchange of even more information on Calder Hall in exchange for similar information on Shippingport. There has as yet been no information at all released on the *Nautilus*.

Concern has been expressed amongst contracting companies over the existing arrangement, and the very valid argument is being put forward that immediately valuable commercial information is being exchanged for information about a reactor system that is only suitable for military usage and can have only a limited bearing on U.K. developments. We have discussed previously the possibility that developments in the *Nautilus* may not even subsequently be relevant to nuclear ship propulsion when applied to merchant ships, whilst the impact of the *Nautilus* developments on the base load programme is likely to be negligible.

We should be the last to suggest that the exchange of information on reactor types is not beneficial to all parties, but a proper perspective must be maintained and any U.S. allegations, particularly in view of past attitudes, treated with the greatest reserve.

REACTOR SAFETY GROUP

A new group has recently been formed in the U.K.A.E.A.I.G. under Mr. F. R. Farmer, which will be responsible for all aspects of nuclear safety. This group will be concerned with the whole of the activities within the U.K.A.E.A. and in order to make coverage complete Dr. A. H. Gillieson, the criticality officer in the Authority, will become a member of the group and will move to Risley. He will also be accompanied by Dr. H. J. Dunster as health physicist. Mr. J. H. Bowen, already at Risley, will be responsible for the engineering side. The group will not only be concerned with the nuclear physics aspects of reactor design, but also with the general mechanical engineering and will function in much the same way as Lloyd's Register of Shipping.

One of the main tasks will be to set up a register comparable to the Shipping Register, so that records can be kept of all reactor installations. Because of the late formation, catching up on designs already agreed will take some time, but it is planned that once the register is established that all reactor designs will receive prior scrutiny and all subsequent modifications recorded. The group will have no direct authority outside the U.K.A.E.A., but as the Authority is consultant to the electricity authorities, and as it plays a major role in reactor siting committees and the like, effective powers of authorization or veto will be absolute throughout the U.K.

The responsibilities the group will carry are, of course, considerable, but the functions that it will perform can be of the utmost value in promoting the development of atomic energy in a safe manner. Initially, it is proper that it should be incorporated within the A.E.A. with access to all available information, but the time will come when a certain amount of autonomy will be necessary and a logical sequence of events would be for the group to be transferred *en bloc* to the Home Office or other Government department normally responsible for industrial good practice and public safety.

U.K. POWER FORECASTS

Based on the demand figures quoted by J. C. Duckworth, of the C.E.A., at the 1955 World Power Conference (*Nuclear Engineering*, **1**, 174) of the probable electrical demand by the U.K. in 1965 and 1975, an estimate is made of the probable contribution that will be made by nuclear power as opposed to conventional means. It is significant to note that even if in the next twenty years 35,000 MW of available capacity is installed the overall annual load factor must steadily rise above that quoted today, which involves the necessity for a progressive attitude towards off-peak loading.

ESTIMATION OF POWER REQUIREMENTS AND INSTALLED CAPACITY

		1955	1965	1975
Demand in MkWh	Total	63,000	136,000	229,000
Average output in MW	Total	7,200	15,500	26,200
Peak output in MW	Total	18,100	34,500	55,500
Available capacity in MW	Conventional	18,845	32,000	25,000
	Nuclear	—	6,000	35,000
Average sent out in MW	Conventional	7,200	11,000	8,000
	Nuclear	—	4,500	18,200
Annual load factor %	Conventional	38.2	34.4	32.0
	Nuclear	—	75.0	52.0
	Overall	38.2	40.8	43.6

GENERATING COSTS

In the Axel Axson Johnson lecture delivered at Stockholm on March 15, Sir Christopher Hinton discussed generating costs of the Calder Hall-type reactor more fully than has been done previously. We reprint below the approximate figures quoted for reactors of the type which have been ordered by the electricity authorities.

Depreciation (5% interest and 20 years' life)	0.37	d./u.s.o.
Interest on fuel charge (5%)	0.06	,,
Fuel replacement charge (£20,000/T.U.) ...	0.24	,,
Operating expenses	0.06	,,
Total	0.73	,,
Credit for Pu in irradiated fuel	0.07	,,
Net	0.66	,,

The analysis is presumably compounded from all the various tenders, and it must be assumed that the figures quoted are conservative. It is understood, for example, that the price for uranium may be lower than £20,000 per ton when the first charge is inserted. The figure of 0.66 pence per unit sent out is not strictly competitive with the best of the conventional stations based on a similar load factor, but Sir Christopher predicted that by 1970 the cost of power from conventional stations would have risen to 0.67 pence per unit sent out, rising to 0.73 pence and 0.84 pence over the next two decades. Predictions were also made of the future costs from nuclear stations, and reasons were given for why this reduction could be expected. The analysis is reprinted below.

Commissioning Date	1960	1970	1980	1990	
Depreciation	0.37	0.30	0.26	0.22	d./u.s.o.
Interest on fuel charge	0.06	0.04	0.03	0.02	,,
Fuel replacement charge	0.24	0.13	0.08	0.06	,,
Operating expenses ...	0.06	0.05	0.04	0.03	,,
Total ...	0.73	0.52	0.41	0.33	,,
Credit for Pu in irradiated fuel ...	0.07	0.05	0.03	0.01	,,
Net ...	0.66	0.47	0.38	0.32	,,

A phrase that seemed to sum up in a concise manner atomic energy developments we feel should also be repeated, viz., "It is a feature of the design of atomic plants that the most daring progress must be made under conditions of the most stringent conservatism".

NERO

A new critical assembly is now in operation at Harwell. Christened NERO, derived from Na Experimental Reactor 0 energy, the system will have a maximum thermal neutron flux of 10^8n/cm^2-sec. and a heat output less than 100 W. Basically, the system consists of a graphite stack which can be varied in size up to a cylinder of 14 ft. diameter by 10 ft. high within a 2-ft.-thick concrete shield. Versatility has been the keynote in the design to allow the greatest flexibility in the investigation of lattice patterns.

One of the most important series of experiments that will be undertaken on this new reactor concerns the physics of burning plutonium in a gas-cooled, graphite-moderated pile. It will be particularly valuable in determining the effect of using a non-homogeneous fuel element, such as a heterogeneous mixture of natural uranium and enriched uranium or plutonium. The results of such research can have a considerable influence on the systems for, and economics of, base load power generation, as the results should indicate the most efficient method of burning plutonium. Included also in the programme for this reactor is a series of experiments for determining the effect of using sodium as a coolant in a graphite-moderated reactor.

"SEAWOLF" PROTOTYPE WITHDRAWN

The U.S.A.E.C. has announced that the experimental sodium-cooled, graphite-moderated, enriched-uranium system developed as a prototype for the *Seawolf* propulsion unit would be closed down. Leaks in the superheater system have given a great deal of trouble, and the general problems associated with sodium technology have caused the A.E.C. to rule that no other sodium-cooled propulsion system would be developed for naval vessels. In its place, General Electric have been given contracts to develop a pressurized-water system for a medium-sized surface craft. It is becoming more apparent that the technology of handling sodium in reactor systems contains far more problems than was at first envisaged, but it may yet be felt that this decision has been somewhat hasty in view of the steady progress made on the SRE project. Construction is now nearly complete, but some time must elapse before the SRE can be made critical, or any worthwhile long-term results obtained. The U.S. navy is now committed to a crash programme of building nuclear-powered ships and, whilst standardization of type may have some advantages, the decision might be regretted in the years to come.

FAST-THERMAL COMBINED SYSTEMS

For some months now the zero energy reactor, ZEPHYR, has been operating as a combined fast-thermal reactor system. Modifications to the blanket were undertaken when the necessary information had been obtained for the construction of Dounreay. This step is a logical extrapolation from results that have already been achieved on the nuclear physics properties of thermal and fast reactors, and the series of experiments now in hand is part of the long-term nuclear physics programme.

In the present set-up a plutonium core is used surrounded by a thin reflector of natural uranium which is, in turn, surrounded by a graphite blanket. The system thus includes the essential characteristics of both the fast and thermal systems and offers the possible advantage of being able to operate a substantially fast reactor with sufficient δk invested in the thermal region to allow ordinary absorber rod control. Whether the nuclear physics of such a system offer advantages over those of a simple fast reactor when the temperature coefficient of reactivity is close to zero (and may be positive) remains to be seen. Similar experiments are under way in the U.S., but it is not envisaged that any alterations will be made to EBR 2; in the same way, the Dounreay fast reactor will operate as a proper fast system.

AVAILABLE CONSTRUCTION EFFORT

The leaders of the contracting consortia have in general, been wary of stating their group's maximum building capacity, but Sir Claude Gibb is prepared to guarantee that the N.P.P.C., as from 1960, will be in a position to complete one double reactor power station in the country and one station abroad per year. Taking 1961 as the first complete year and assuming that the three other original consortia can do likewise, with Atomic Power Constructions Ltd. one year behind, the total completed by 1965 would amount to 19. Presumably this figure is not a coincidence. If, in addition, we can have exported 18 power stations, plus the Northern Ireland one, by the same date we can be well satisfied.

Site Organization at Calder Hall

by

J. F. VARCOE, B.Sc., A.M.I.C.E., M.Inst.H.E.

Chief Engineer, Calder Hall, Taylor Woodrow Construction Ltd.

The tight constructional programme demanded by the U.K.A.E.A. presented the contractors with an exercise in planning and organization calling for the most efficient use of materials, plant and labour.

THE contract for the civil engineering work for Calder Hall "A" was invited as a prime cost contract and let on that basis on July 22, 1953. At that time the civil engineering design was handled by the Ministry of Works, which acted as consulting engineers to the Department of Atomic Energy (then forming a branch of the Ministry of Supply). This arrangement was changed in August, 1954, when the United Kingdom Atomic Energy Authority was born and staff from both Ministries had the opportunity of transfer to the U.K.A.E.A. or of being seconded to it until their place could be filled permanently.

The contract, as originally let, was for the construction of one reactor, turbine hall and administration block, together with temporary offices and ancillary works consisting of roads, drainage, water supply, fencing and police lodge. This was extended in October, 1953, to include a second reactor and in June, 1954, two cooling towers were added. These works comprise Calder "A"; and in July, 1955, the contract was doubled in size by the decision to build Calder "B". The total value when completed will approximate to £5 million. The structural steelwork, discussion of which is omitted, was the only civil engineering and building trade which did not fall within the scope of the contract awarded to Taylor Woodrow Construction Ltd.

At the time of letting, the contractor was warned that a prime cost form of contract had been chosen in order that construction could follow immediately upon design. The Authority would endeavour to issue working drawings four weeks before construction was programmed, but amendments and even cancellations were inevitable. Despite these anticipated frustrations, however, the tight programme which was demanded had to be maintained.

Major Items of Plant

One 15-ton derrick	Two 5/3½ concrete mixers
Four 10-ton derricks on 40-ft. gabbards	Two mortar pans
	One Airslide bulk cement equipment
Four 7-ton derricks	Four swing weigh batchers
One 5-ton derrick	One No. 3 Cumflow concrete mixer
One 10-ton mobile crane	Twenty-seven internal vibrators
One 6-ton mobile crane	One D.6 bulldozer
Eight 30-cwt. goods hoists	One D.4 bulldozer
Three six-person passenger hoists	Two two-tool mobile compressors
One 33 R.B. excavator	Six four-tool mobile compressors
Five 19 R.B. excavators	Four 75-kVA Diesel generators
Two 1 cu. yd. concrete batching plants	Two agricultural tractors
	Ten 1 cu. yd. dumpers
Two 21/14 concrete mixers	Twenty 5-ton tipping lorries
Two 14/10 concrete mixers	One 8-ton Diesel roller

In addition, there were numerous small tools, pumps, rammers, vans, vertical steam boilers, scaffold hoists, and bar cutting and bending equipment.

A completely equipped plant workshop contained a 7½-in. lathe, 3-ft. radial drill, power saws, a screw-cutting machine and the usual small tools and equipment.

The joiners' shop contained a 26-in. circular saw and a 6-in. planing machine as well as sanders, saws and other powered hand tools.

View of Calder Hall taken at the time of the official opening by H.M. the Queen.

The problems associated with this contract were very largely ones of planning, organization and production rather than technical difficulties, although a standard of workmanship not normally associated with power stations construction was demanded. Complete information was also not always available until immediately before the beginning of an operation; the issue of drawings was not automatically an order to proceed. A written order from the site architect was necessary before materials could be ordered and work put in hand, and from time to time site works orders were issued by clerks of works which altered or amplified the work shown on the drawings. Steel-bending schedules were not issued, and therefore the late arrival of a structural detail drawing imposed an extra burden on the section engineer responsible for that portion of work. Inherent in the contract was the necessity for the establishment of a cost accounting system, an approved incentive bonus scheme and a method of stores accounting.

Quarterly, the Authority's quantity surveyors prepared a cost comparison between actual expenditure and a notional cost of the job on a normal measured basis. All extras and amendments therefore had to be costed separately and added to the "normal measured basis" to arrive at a sensible notional cost. This necessitated the establishment of a large surveying and costing site staff.

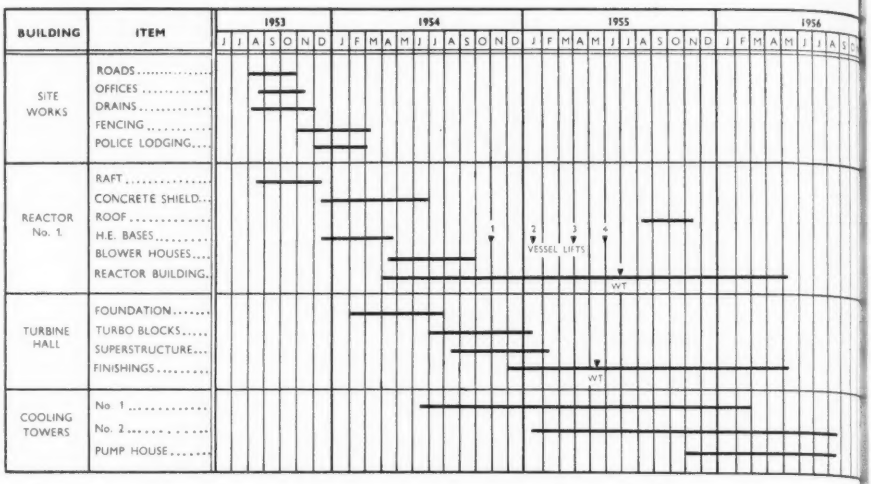
Owing to the nature of the contract, it was convenient for the civil contractor to supply and maintain plant (particularly derricks) for use by mechanical and electrical contractors, and also to lend certain items for short periods. Adequate insurance cover and a clearly defined responsibility were very necessary in these cases.

Office Organization

Under this form of contract all expenditure legitimately incurred and approved by the Authority was admissible to prime cost. This included wages or salaries for all site staff, cost of running the labour camp and all welfare staff, sub-contract accounts, materials and consumables, buses

for the transport of labour from certain areas, and insurances and office expenses. Water, telephone, electricity and steam were free on site. Charges for head office services were not, however, admissible and service departments normally associated with head office were established on site. Buying, accountancy, quantity surveying, and cost and bonus each carried a complete staff.

Engineer, wages, timekeeping, checking and stores were the usual contractor's site departments, with the exception that in the time office and in the stores the Authority had permanent checkers established to keep a running check on clock cards, time sheets, bin cards, etc.



Master programme covering the building operations.

Security

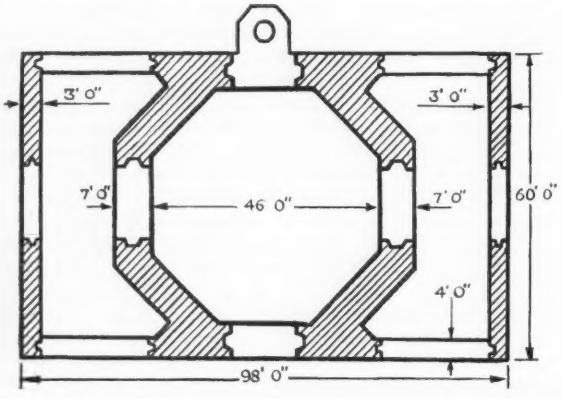
After seven months the site was completely fenced, and was policed by the Authority. Personal passes were issued, with car passes to those entitled to bring their private vehicles on site. Any materials or plant taken off site had to go out under a property pass which was issued by the resident engineer. This system also covered such items as empty crates being delivered to the railway station for return to suppliers.

All staff and labour had to have clearance from security before admission to site and access to confidential drawings and other documents. All offices had to be secured at night and drawings put away in locked plan chests. Security wardens were used in addition to the police to enforce these regulations.

Programming and Co-ordination

In addition to the drawings and instructions to proceed, a master programme covering the whole contract and submaster programmes for each reactor, turbine hall or other major section of work, were issued to the contractors. It was necessary to prepare, and then to get Authority approval for, detailed working programmes which elaborated these master programmes.

Here we have the key to one of the vital differences between this and the normal type of contract. The reactor, for instance, could logically be divided into the following sections: raft foundation; biological shield; control building; pile cap buildings; discharge buildings; long blower house; short blower house; and ancillary buildings.



Plan of reactor building, showing the division into 18 construction bays.

Each of these sections would have one or more "key dates" which had to be met to enable mechanical or electrical contractors to carry out a portion of their work. It quickly became obvious that even if it were possible to improve materially on these dates it would not be desirable, as this might disorganize the mechanical and electrical contractors on previous portions of their work. A complicated pattern was built up, therefore, showing the dovetailing of operations by as many as eight main contractors, together with their numerous sub-contractors.

The co-ordination of these often-conflicting interests was hammered out for the first reactor in many and lengthy planning meetings. For subsequent reactors it was found that the time and thought had been well spent and that only a slight readjustment or streamlining was needed to relate reality to the original theory.

As an example of a detailed programme, the concrete main structure of the biological shield, octagonal in plan with walls 7 ft. thick and approximately 90 ft. high, can be cited. The structure was divided into 18 bays as shown and constructed in twenty 4 ft. 6 in. high lifts. There were over 300 separate bays of concrete, most of which contained tubes, thermocouples, openings, cages and fixing plates. It was specified that three days must elapse between adjacent pours.

The concreting operation was so programmed that it defined on what date each bay should be poured, allowance being made for the time taken for setting up in each bay, time off for public holidays, etc. It was decided to programme assuming five working days in the week, the remaining working time being considered to offset time lost due to inclement weather. It was proved by experience that this arbitrary allowance worked out very accurately.

Programmes are valueless unless progress keeps strictly in step, and the contractor held weekly progress meetings at which all engineers and foremen attended. Here was discussed the success or failure of the previous week's efforts and the intentions for the following week. An Authority's civil progress meeting was held monthly, at which the deputy resident engineer took the chair and was attended by the contractor's representatives, structural engineers and architects from Risley. It is felt that these meetings would have been of even more value had a

representative of the mechanical and electrical interests been present.

Site Supervision

The contract was under the control of an agent who had as his main assistants a chief engineer and deputy agent, and a works manager.

Other staff consisted of two sub-agents, five engineers, six foremen, two plant staff, two checking and stores, and six or seven trades foremen.

Normally, on each section, the foreman was responsible for labour and site organization, the engineer being responsible for setting out, accuracy, materials progressing and information. The sub-agents formed the link between the works manager and the foremen, whilst a senior engineer linked the chief with the section engineers.

It was the endeavour of this staff to maintain the accuracy demanded, and at the same time to organize and run the contract as efficiently and economically as they would have had it been at a fixed price.

Before the start of the contract great stress was laid on the need for extreme accuracy and quality of workmanship, particularly on the biological shield concrete, where high density was of great importance, and other reactor work. Design and control of concrete mixes was carried out in a laboratory set up by the Authority, who checked the water content of aggregates and took sample test cubes several times daily.

Before the shield walls were commenced a full-size mock-up, containing typical tubes and thermocouple boxes, was concreted. This was then demolished to see if complete compaction had been achieved and that no voids had escaped notice, particularly on the undersides of the embedded equipment. During actual construction, there was never any trouble of this nature, nor was any concrete pour marred by honeycombing.

Labour

A peak labour force of 750 men was employed on Calder "A", but this rose to over 1,100 men with the advent of the Calder "B" contract. Owing to the nature of the work, there were rather more skilled than unskilled men employed. A feature was the very large force of scaffolders, which at one time exceeded 100. Staff totalled 70, comprising 26 technical, 29 clerical and 15 welfare.

To maintain the rigorous programme, and at the same time to maintain the labour force in the very isolated location of West Cumberland, a working day from 7.45 a.m. until 7 p.m. was instituted, with alternate working week-ends. The working week thus averaged approximately 60 hours. This was maintained throughout the year by the installation of extensive site lighting.

Good labour relations were established early in the contract and disputes were few and of very minor importance. The success in this respect was in no small measure due to the efforts of a full-time labour officer. Some 400 men lived locally and travelled either by train or bus to the site. The remainder were housed in a camp, two miles from the site, with a capacity of 640 men. The camp was made as attractive as possible with a cinema, clubroom, wet canteen, etc. A welfare committee organized concerts and sporting events. Amenity buses were run twice weekly in the evening to nearby towns.

Work on site was carried out under the civil engineering working rule agreement.

Normally materials were requisitioned from drawings, by the quantity surveyors, to the buyer. A minimum of three quotations was obtained, with samples if necessary, and submitted with a recommendation by the buyer to the Authority, on a purchase-approval form. This was endorsed by the Authority's quantity surveyor and deputy resident engineer, after which the official order was placed.

Bulk orders were placed for such materials as cement, aggregates and bricks, and deliveries were called forward as required.

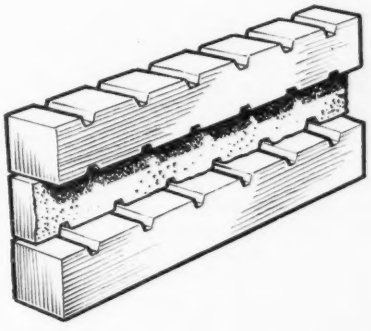
Some difficulty was experienced in regulating the delivery of bulk cement. This came in containers by rail from Hull and was normally three or four days in transit. Storage capacity on site was 500 tons, the equivalent of some 2,500 cu. yd. of concrete. With a peak output of concrete for one week of 2,200 cu. yd., but with an average output of only 800 cu. yd. per week, there were times when the silo was empty, and deliveries were suspect. At other times, with a full silo, demurrage was incurred on containers which could not be emptied.

Stock piles of sand and large aggregate were established, as these materials had to reach the site over fell roads which were frequently blocked by snow during the winter. The site itself, however, suffered very little from snow or frost owing to its proximity to the western seashore. Steam heating of aggregates and mixing water was installed for winter use.

Plant

Plant was brought to site and removed therefrom through a purchase approval routine, similar to that employed for materials.

Under the terms of the contract, plant was valued as it came on to the site by an independent firm of plant valuers and that valuation was admissible to prime cost. Plant was also valued off site in a similar manner and the sum deducted from prime cost. Of the non-mechanical plant, scaffolding was by far the heaviest item. Some 750,000 linear feet of tube and 175,000 scaffold fittings were in use at one time. Here again, much scaffolding was provided for the use of other contractors.



Permanent stop ends cast in concrete were used to locate the reinforcement bars in the reactor raft foundations.

Departures from Conventional Practice

Reference has been made to the high standards of workmanship demanded, and the differences between this and conventional power-station construction.

In the reactor raft foundations, for instance, the bottom slab is reinforced with three mats of $1\frac{1}{8}$-in. diameter bar at 6-in. centres both ways, and spaced 6 in. apart. Temporary stop-ends in timber were considered impracticable and permanent stop-ends cast in concrete were used. These had the added advantage that they rigidly located the bars and made placing easier.

Steel-framed buildings abut the outside of the octagon concrete and, of necessity, are fixed thereto. To avoid the hindrance to shuttering caused by corbels or pockets to carry the steel beams, steel fixing plates were cast into the

Dig:	300,000 cu. yd.	**Cooling Tower**		**Biological Shield Concrete**	
Concrete:	150,000 cu. yd.	Height:	300 ft.	Aggregate/cement ratio:	6.3:1
Reinforcement:	6,000 tons	Octagonal pond width:	220 ft.	Water/cement ratio:	0.52:1
Bricks:	3,650,000 No.	Column diameter:	16 in.	Specified dry density:	150 lb./cu. ft.
Timber:	1,300 standards	Columns:	64 No.	Specified 28-day strength:	3,000 lb./sq. in.
Reactor		Ring beam diameter:	190 ft.	Average wet density:	159.3 lb./cu. ft.
Length:	290 ft.	Throat diameter:	104 ft.	Average 28-day strength:	6,094 lb./sq. in.
Width:	130 ft.	Concrete in shell:	2,200 cu. yd.	Lowest 28-day strength:	4,230 lb./sq. in.
Roof height:	120 ft.	Concrete in pond:	1,700 cu. yd.	Highest 28-day strength:	7,780 lb./sq. in.
Dig:	27,000 cu. yd.	Concrete mix:	5.5:1	Standard deviation:	776 lb./sq. in.
Concrete:	18,000 cu. yd.	Reinforcement	350 tons	Total quantity:	40,000 cu. yd.
Reinforcement:	700 tons				

concrete with their faces flush with the concrete surface and held securely by large welded fangs at the back. Angle cleats were later welded to these plates to carry beam ends.

The envelope space outside the octagon, but within the shield wall, was divided by floors at four levels. In order not to hinder the progress of the octagon, these floors were omitted during the octagon construction and were carried on R.S.J.s supported by the beam fixing plates; they were also notched into indents in the walls. These indents, usually about 6 in. deep, were formed by $\frac{3}{4}$ in. mesh expanded metal lathing fixed to reinforcing bar, and provided a permanent stop-end. With the low water/cement ratio in the mixes used, little trouble was experienced due to grout losses.

All construction joints in the biological shield were hacked 100% before adjacent concrete was placed. This was to ensure that no straight path existed for the escape of radiation. Horizontal joints had at least an inch taken off by hand-picking, whilst all vertical joints were bush hammered.

"Clean conditions" was a term widely used and denoted the need in certain areas for a hospital standard of cleanliness. This was to prevent dirt or any other matter getting inside the reactor itself or in any of the gas circuits. Clean conditions involved the provision of change and locker rooms, and showers and toilet facilities for those working inside the pressure vessel or heat exchangers. It is worthy of note that the set-up for the graphite-handling squad occupied the third and fourth floors in the control building and covered an area of 6,000 sq. ft.

Incompatibility was of importance in areas where fuel elements were likely to be handled. Metallic substances with significant cross-sections would become a source of danger should small particles become detached. To combat this, brass, copper and zinc fittings were treated with shellac and decoration was carried out with metal-free paint.

Summary

The Calder Hall contract presented an exercise in planning and organization and called for efficient use of materials, plant and labour. Of these three, the labour force is the most variable, and it was essential that this was established quickly, both as regards quantity and quality. It was the task of the management to weld into one enthusiastic team the diverse personalities, both staff and operatives, at its disposal.

The steps taken to make this contract attractive to the site operatives should be re-emphasized. These included a long working week with its large pay packet, available throughout the whole year; an efficient incentive bonus scheme; and the camp for those living away from home providing good food and recreational facilities. All these helped to create the enthusiastic effort which was so necessary.

The staff at their weekly progress meetings discussed methods to meet the demands of the programme and their pride in achievements was communicated to the gangs in the field.

Special tasks were made of specific jobs, such as the concreting of turbo-alternator blocks, reactor rafts, walls and roof slabs, etc. Briefing meetings were held at which charge-hands and gangers attended and quality bonus was paid in addition to the normal bonus for quantity. By methods such as these, everyone on the site was encouraged to feel that he had a personal interest in the work in hand.

Looking back over the past three and a half years, the company is convinced that this approach to the problem was largely responsible for the overcoming of all the many difficulties and frustrations of which it had been warned at the start.

L'organisation des Lieux à Calder Hall

Les problèmes découlant de la construction de Calder Hall étaient principalement des problèmes de conception, d'organisation et de production, plutôt que d'ordre technique, bien qu'un degré d'exécution qui n'est pas normalement associé à la construction de centrales électriques aut été requis. Les rapports entre l'entrepreneur et la Direction de l'Energie Atomique du Royaume-Uni sont examinés dans leurs grandes lignes et des détails sont fournis de la quantité et de la qualité de la main-d'œuvre ainsi que des mesures prises pour rendre les travaux attrayants aux ouvriers employés sur le chantier. De bonnes relations de patron à employé ont été principalement responsables de la vitesse et de la capacité auxquelles les travaux furent terminés.

Die Organisation beim Bau von Calder Hall

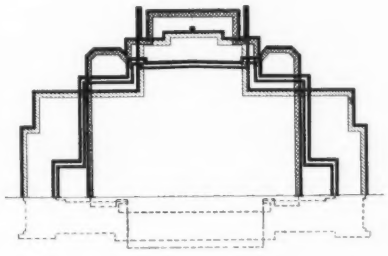
Die Probleme, die beim Bau von Calder Hall zu lösen waren, waren wesentlich solche der Planung, der Organisation und der Produktion und weniger solche technischer Art, obwohl ein Standard der Arbeit verlangt wurde, wie man ihn meistens nicht bei der Errichtung von Kraftwerken verlangt. Das Verhältnis zwischen dem Bauunternehmer und der U.K. Atomic Energy Authority wird erklärt, und es werden Einzelheiten über die Anzahl der Arbeitskräfte und deren Qualität gegeben, ferner über die Schritte, die unternommen wurden, um dies Unternehmen für die Leute auf der Baustelle anziehend zu machen. Das gute Verhältnis zu den Arbeitskräften hat zu einem grossen Teil dazu beigetragen, dass die Arbeiten so schnell and so gut bis zum Ende durchgeführt wurden.

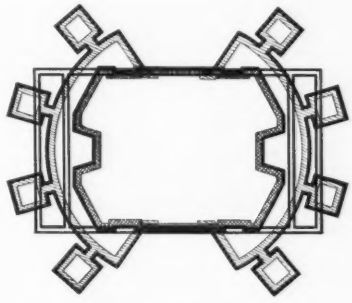
Organización del Sitio en Calder Hall

Los problemas asociados con la construcción de Calder Hall eran mayormente más bien problemas de planeado, organización y producción que técnicos, aunque, naturalmente, se exigió una norma de mano de obra no asociada generalmente con la construcción de centrales de fuerza. Las relaciones entre el contratista y la Autoridad Atómica del Reino Unido son bosquejadas y se ofrecen detalles de la cantidad y la cualidad del equipo de obreros y de los pasos que se dieron para hacer que el contrato resultara atrayente a los operarios en el sitio. Las buenas relaciones con los obreros fueron mayormente responsable por la rapidez y la eficiencia con que estas obras fueron llevadas a cabo.

The New Stations — A Detailed Comparison

Superimposed elevations and plans are shown of the three nuclear power stations specified in the contracts placed by the Central Electricity Authority and the South of Scotland Electricity Board. The major characteristics of the stations are given in the table following. Composition of the main U.K. contracting consortia is appended together with the names and make-up of other combines and companies who are prepared to consider the construction of nuclear power units.





	A.E.I.-John Thompson	G.E.C. Simon-Carves	Nuclear Power Plant Co.
Location	Berkeley, Glos.	South Scotland	Bradwell, Essex
Operation	First reactor mid-1960	—	First reactor mid-1960
	Second reactor early 1961	—	Second reactor end 1960
	Ground broken January 7	—	Ground broken January 18
Output	275 MW	300 MW	300 MW
Uranium charge	250 tonnes	251 tonnes	240 tonnes
Fuel element length	18 in. (approx.)	24 in.	36 in.
Number of channels	3,000	3,288	2,620
Canning material	Magnesium alloy Magnox A12	Magnesium alloy Magnox A12	Magnesium alloy Magnox A12
Element support	Graphite struts with zirconium end brackets	Graphite sleeves loaded with cartridge	Stacked
Core size	42 ft. dia. × 24 ft. high	44 ft. 6 in. dia. × 23 ft. high	40 ft. dia. × 25 ft. 8 in. high
Overall size	48 ft. × 30 ft. high	50 ft. 6 in. × 27 ft. high	45 ft. × 31 ft. high
Graphite weight	2,000 tonnes	2,150 tonnes	1,910 tonnes
Lattice	Sq. 8.16-in. pitch	Sq. 8¼-in. pitch	Sq. 8-in. pitch
Pressure vessel	Mild steel, double skinned, top charging	Coltuf 28, double skinned, bottom charging	Special steel, top charging
Shape	Cylinder	Sphere	Sphere
Dimensions	50 ft. dia. × 80 ft. high	70 ft. dia.	66 ft. 9 in. dia.
Shell thickness	3 in.	2⅝ in.	3 in.
Support	18 A-frames	Skirt	24 frames
Gas pressure	125 p.s.i.	150 p.s.i.	150 p.s.i.
Inlet temperature	160°C	204°C	180°C
Outlet temperature	350°C	396°C	390°C
Ducts	Eight inlet and outlet	Eight inlet and outlet	Six inlet and outlet
Diameter	5 ft.	5 ft.	5 ft.
Circulators	Single-stage axial	Vertical shaft centrifugal	Single-stage axial
Drive	a.c. induction motors, scoop-control fluid coupling	d.c. motors fed by grid-controlled rectifiers	Variable frequency induction motors fed from turbo-generator
Speed	580/2,900 r.p.m.	200/1,000 r.p.m.	600/3,300 r.p.m.
Control-rod drive	Variable-frequency induction motors	Variable-frequency induction motors	Variable-frequency induction motors
Boilers	Eight per reactor	Eight per reactor	Six per reactor
Dimensions	17 ft. 6 in. dia. × 70 ft. high	20 ft. dia. × 70 ft. high	19 ft. dia. × 87 ft. high
H.P. steam temperature	612°F	700°F	700°F
H.P. steam pressure	320 p.s.i.a.	590 p.s.i.a.	765 p.s.i.a.
L.P. steam temperature	612°F	570°F	700°F
L.P. steam pressure	77 p.s.i.a.	160 p.s.i.a.	209 p.s.i.a.
Turbo-alternators	Four	Six	Six + three auxiliaries
Individual Rating	85 MW	60 MW	52 MW+5% margin and 20.5 MW
Shielding	8 ft. 6in. to 10 ft. concrete, 1 ft. 5 7/16 in. steel	9 ft. to 10 ft. 6in. concrete	9 ft. to 10 ft. concrete

A.E.I.-JOHN THOMPSON NUCLEAR ENERGY CO. LTD.
Associated Electrical Industries Ltd.
John Thompson Ltd.
Balfour, Beatty and Co. Ltd.
John Laing and Son Ltd.

G.E.C. SIMON-CARVES ATOMIC ENERGY GROUP
General Electric Co. Ltd.
Simon-Carves Ltd.
Motherwell Bridge and Engineering Ltd.
John Mowlem (Scotland) Ltd.

THE NUCLEAR POWER PLANT CO. LTD.
C. A. Parsons and Co. Ltd.
A. Reyrolle and Co. Ltd.
Head, Wrightson and Co. Ltd.
Sir Robert McAlpine and Sons Ltd.
Whessoe Ltd.
Strachan and Henshaw Ltd.
Alex. Findlay and Co. Ltd.
Clarke, Chapman and Co. Ltd.
Parolle Electrical Plant Co. Ltd.

ENGLISH ELECTRIC-BABCOCK AND WILCOX TAYLOR WOODROW
The English Electric Co. Ltd.
Babcock and Wilcox Ltd.
Taylor Woodrow Ltd.

ATOMIC POWER CONSTRUCTIONS LTD.
Crompton Parkinson Ltd.
International Combustion (Holdings) Ltd.
Richardsons, Westgarth and Co. Ltd.
Trollope and Colls Ltd.
Holland and Hannen and Cubitts Ltd.

Vickers Nuclear Engineering Ltd.
Vickers Ltd.
Rolls-Royce Ltd.
Foster Wheeler Ltd.

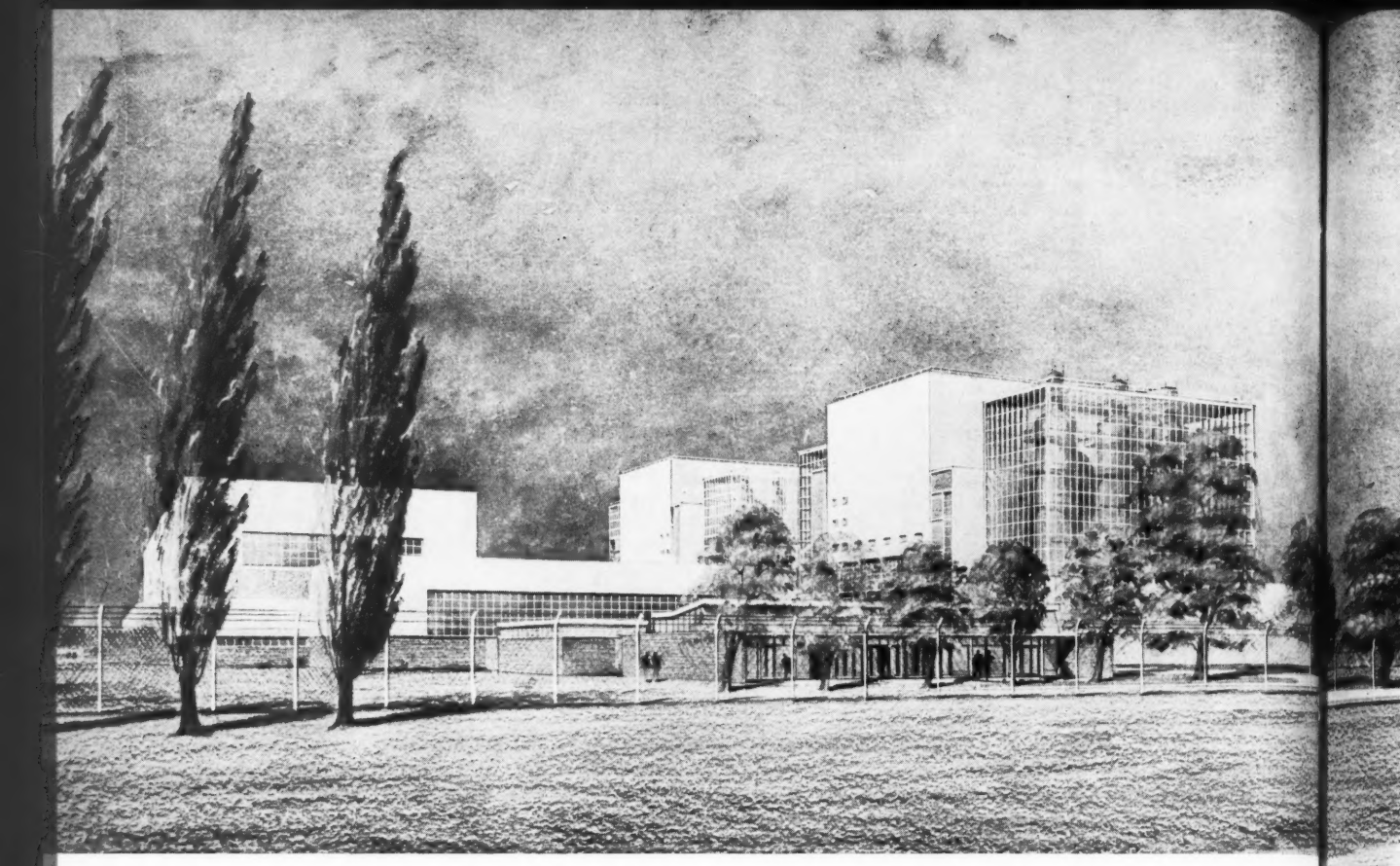
Mitchell-A.M.F.
Mitchell Engineering Ltd.
A.M.F. Atomics Inc.

Humphreys and Glasgow Ltd.-Alco Products Ltd.
Humphreys and Glasgow Ltd.
Alco Products Ltd.

Hawker Siddeley Nuclear Power Co. Ltd.

Head, Wrightson Processes Ltd.

Ruston and Hornsby Ltd.



1. Optimization of the N.P.P.C. Design

By R. D. VAUGHAN, B.Mech.E.(Melb.), A.M.I.Mech.E.

Chief Engineer, N.P.P.C.

THE two basic requirements of a power reactor are low cost operation and trouble-free operation. The first requirement calls for careful selection of all the design parameters to give the best combination of fuel rating, cycle efficiency and fuel irradiation time for low generation cost. The second implies close attention to the reliability of all plant components, both inside and outside the reactor; in other words, good engineering design. These two requirements are not necessarily compatible with one another.

Where there is a free choice for a particular parameter, and there are no engineering limitations, that parameter may be selected on purely economic grounds to be the value for which generation costs are a minimum. In other cases there may be a clearly defined optimum which cannot be reached because of a metallurgical or constructional restriction. This would apply, for example, to the diameter of the main gas ducts. There is a third type of parameter for which there appears to be no particular optimum, with costs continually falling in one direction, and here again the choice is made on purely engineering grounds; examples are fuel temperature and gas pressure.

Capital Costs

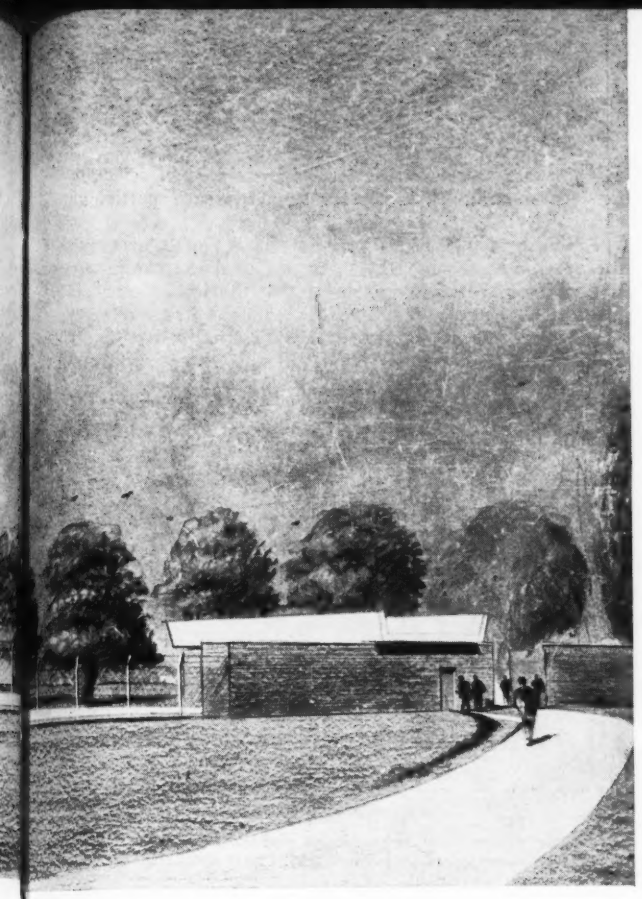
In general, it is sufficient to optimize for lowest specific capital cost, which usually makes the major contribution to generation cost. This is not quite adequate when fuel irradiation time has to be considered as a variable. If there were no metallurgical restriction on the life of a fuel element, one could probably justify spending more money on the core in order to secure more reactivity and longer irradiation of the fuel.

The majority of design parameters cannot be settled independently of one another. and for this reason it is not possible to work methodically through a design selecting each parameter in turn.

Shape of Reactor Vessel

The sphere has a lot to commend it from the engineering point of view when compared with a cylinder; increased gas working pressure, superior design of reinforcement at duct entries, less angular deflection in the outer standpipes under pressure. However, the large equatorial diameter calls for more concrete in the biological shield and a generally larger reactor building and foundation raft. It is necessary, therefore, to calculate generation costs with both spherical and cylindrical vessels before making a choice.

Assuming that facilities are available to press spherical plate segments of any thickness required, the sphere can be justified on economic grounds for reactors of large output. However, for small outputs, for example, Calder, it may be shown that the cylinder is cheaper. The comparison depends partly on the space requirement above the core for manœuvring the charging equipment. The height required for this equipment to function will remain substantially constant with reactor cores of different dimensions, and with small cores it would therefore become an embarrassment in a spherical vessel. Hence, at small outputs there is an economic case for the cylinder.



Bradwell-on-Sea Nuclear Power Station

The Nuclear Power Plant Co. is building for the C.E.A. what is claimed will be the first nuclear power station to generate electricity at an economic price. Guaranteed net output is 300 MW. The total installed generating capacity of the station is 390 MW, the extra 90 MW being provided partly for station auxiliaries and also as a margin to allow for subsequent increases in reactor output.

Number of Gas Circuits

The smallest possible number of gas circuits per reactor would normally be the cheapest, except that extra power is required for gas circulation, and the capitalized value of this may become comparable with the amount saved elsewhere. There are also several possible engineering limitations; for example, the physical size and weight of each boiler vessel, the capacity of the motor driving the gas circulator. In practice, these limitations are reached before the power losses in the ducts become a problem.

With a small number of circuits the opportunities for gas leaks are reduced, and a more compact and straightforward arrangement of blower house becomes possible. In the case of Bradwell, with six circuits there was the added incentive of keeping down the dimensions of the Goliath crane which spans the whole building.

Reactor Core Dimensions

The reactor physicist always prefers a core with good geometry, which means, in the case of a right cylinder, a value of the ratio, length/diameter approaching unity. He is usually confounded by the heat-transfer engineer who wants a flat core of large diameter to give him a large number of short channels.

The engineer's difficulties can only be resolved if he has a high gas pressure and a fuel element which will transfer its heat effectively without too much resistance to gas flow. Then the core with good geometry becomes possible, and the following advantages come with it. The number of channels is reduced and the standpipes and other facilities provided for charging are therefore cheaper. The reactor vessel can be reduced in size to help increase the gas pressure and save cost.

However, the chief advantage is the good nuclear design, implying more flattening and higher mean fuel rating or longer fuel irradiation, whichever is preferred.

Operating Temperatures

The choice of reactor gas inlet and outlet temperatures is probably the most interesting in the whole design. It is also quite critical, and yet the wide range of conclusions reached for the reactors recently submitted to the Central Electricity Authority suggests either that the design of each particular reactor has a marked effect or else the methods employed are still far from reliable.

In order that the incoming gas should pick up as much heat as possible while it passes through the core, it should enter at a low temperature. This also reduces the blowing power. Unfortunately, it also depresses the low-pressure steam conditions and the final feed-water temperature, both of which affect the efficiency of the steam cycle adversely. The choice of this temperature is made by straightforward optimization.

The gas outlet temperature is controlled chiefly by the maximum allowable fuel can surface temperature defined by metallurgical considerations. A high gas outlet temperature would require good heat transfer in the fuel channel and a fairly high blowing power to overcome the channel resistance associated with good heat transfer. The efficiency of the steam cycle would be high. A low gas outlet temperature would, on the other hand, mean a low blowing power but low steam cycle efficiency. It is not immediately evident which of these two combinations is the better.

The heat-transfer performance of the fuel element secondary surface is affected by several variables—number of fins, height of fins, configuration of fins, and also the channel diameter. With these variables it is possible to secure any behaviour required, and thence any chosen gas temperature. The result of such a consideration is a curve of generation cost against gas outlet temperature as shown in Fig. 1. Here it will be seen that the optimum temperature is defined to within a few degrees.

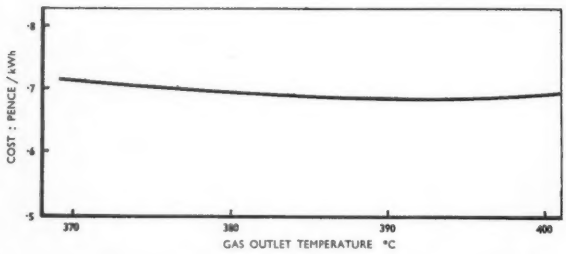


Fig. 1. Generation cost as a function of gas outlet temperature.

Steam Cycle

With a single-pressure steam cycle, and an assumed approach temperature, there is only one possible steam pressure and corresponding cycle efficiency. A reduction in approach temperature would give a slight improvement in cycle efficiency at the expense of increased tube surface in the boiler, but the cost of extra surface very quickly becomes prohibitive.

The dual-pressure steam cycle offers marked improvements in efficiency over the single-pressure cycle which fully justify the cost of extra steam drums and external piping. Moreover, it has an important advantage over the single-pressure cycle in that it assists stability of control of the reactor inlet temperatures in a system which is required to have normal Grid frequency-load regulation.

Principles of Design

For trouble-free operation the design and functioning of the reactor should be as simple and straightforward as possible.

One important criterion is that there should be inside the reactor vessel the absolute minimum of equipment which cannot be removed for inspection or replacement. This applies particularly to mechanisms. Hence it is desirable that the charging mechanism be completely removable and independent in its operation. The bulk of the equipment in the core for detecting fission products should also be removable. This can be done by grouping the pipes in clusters passing up through the control-rod standpipes.

In order to avoid shutting the reactor down for refuelling, it is necessary to be able to carry out this operation at full load. The charge machine must therefore be brought to the reactor vessel, connected up, and a grab or plunger introduced into the core without interrupting the flow of gas through the channels. Opinions vary on the design of fuel element which can most easily be handled under these conditions, and both stacked and individually supported designs have been put forward.

The virtue claimed for the stacked design is that it has no moving parts and all the components can be made of the same material, which may then conveniently be welded together. In this design much more emphasis must be placed on producing a fuel element which will not deform under the axial load of the elements above. The alternative system of individual support involves mechanisms which must alight on steps in the channel wall or graphite cages, which are themselves stacked upon one another.

For ease of operation it would be very desirable to employ a uniform channel throughout the reactor core, and hence only one design of fuel element and charging mechanism. With certain high-performance fuel elements this is possible, but, of course, there is a small penalty in reactivity. With only one type of element, the charging-machine operator is relieved of the problem of selecting by remote control the correct sizes for each particular channel.

The reactor unit itself, excluding civil works, accounts for approximately half the total cost of a nuclear power station. It is therefore important that the load factor on it be as high as possible, and there must be no enforced shut-downs due to faults in the external conventional equipment: it is just as important then for the turbo-alternators, transformers and switchgear to be made simple and robust as it is for the reactor core. For some components 100% spare capacity is justified on this score, in spite of the additional cost.

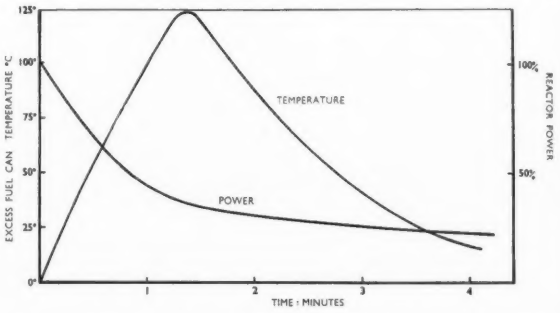


Fig. 2. Temporary fuel temperature rise and loss in reactor power for failure of all circulators and the reactor trip circuit.

Safety

Power reactors will in due course be located near large towns where the load is required. Therefore, every opportunity should be taken to improve the inherent safety which already exists in the gas-cooled, graphite-moderated reactor. In addition to the good negative temperature coefficient of reactivity, there are two very important mechanical features which can be incorporated without much difficulty.

By increasing the inertia of the gas circulators, a long run-down time in the event of failure of supply can be ensured. The flow of gas under these circumstances is then maintained as long as possible.

The other feature is the natural circulation of the gas at operating temperatures. By dropping the reactor core (the heat source) as far as possible with respect to the boilers (the heat sink), it is possible to obtain a circulation flow of about 10% of full-load flow with all the circulators out of action.

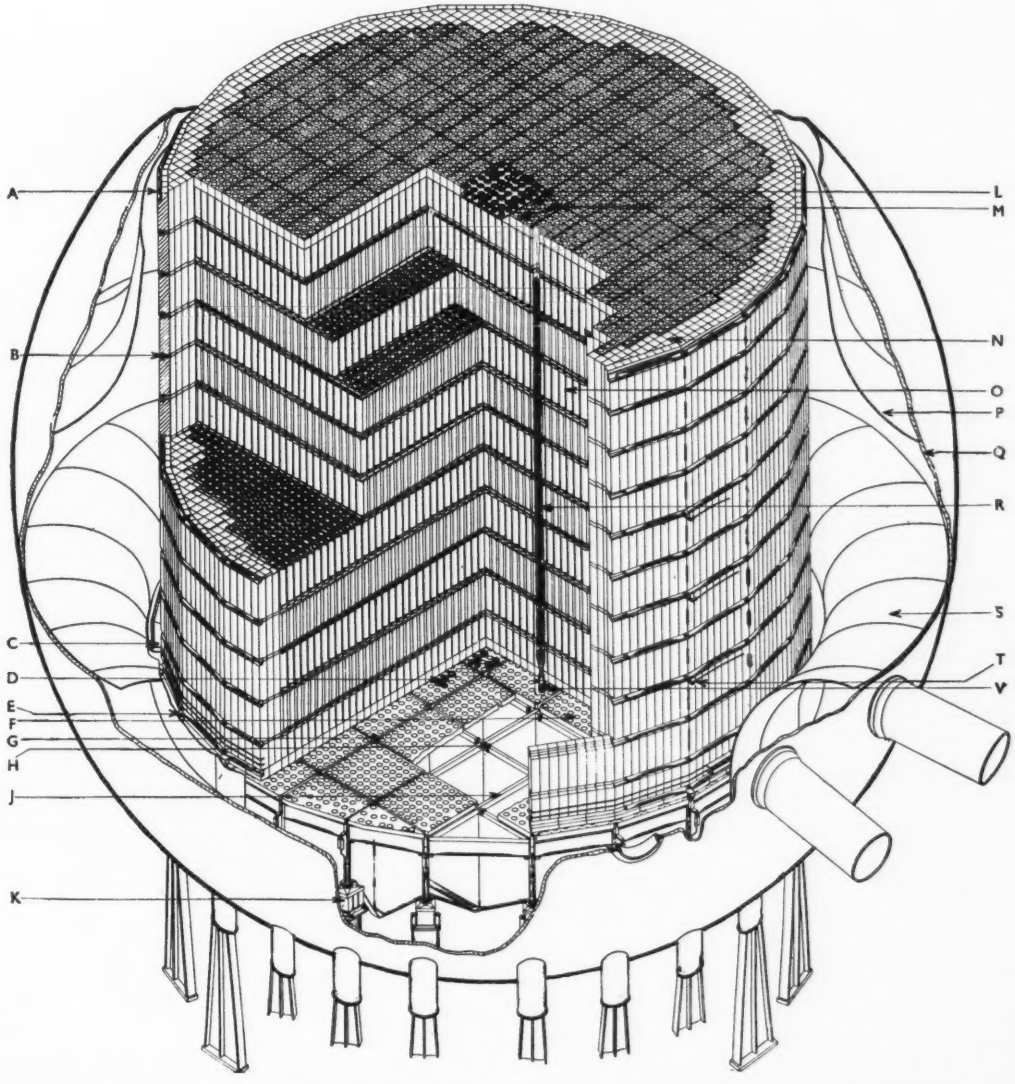
The combination of all these features enables the plant to accommodate quite serious faults without the fuel elements rupturing. The curves in Fig. 2 show the temporary rise in fuel temperature and the loss in reactor power for a simultaneous failure of all gas circulators and the reactor trip circuit. The maximum rise in fuel surface temperature is 125°C, which would not take it through the melting point of the can material. In other words, if all the instrumented safety devices and standby supplies were to fail, the reactor would still be inherently safe.

KEY FOR SECTION OF REACTOR CORE ON OPPOSITE PAGE

A Topside restraint. B Intermediate side restraint. C Gas seal. D Graphite support bearing. E Bottom side restraint and radial keys. F Support plates. G Levelling screws. H Levelling pads. J Diagrid. K Roller supports. L Charge pan. M Charge pan support. N Reflector bricks. O Moderator bricks. P Gas baffle. Q Pressure shell. R. Fuel element. S Toroidal shield. T Wigner growth measuring device. V Fuel element support lantern.

2. General Description of the Bradwell Station

OF the same type as the Calder Hall plant, in the construction of which members of The Nuclear Power Plant Co. played a major role, the Bradwell station will necessarily exhibit some of the basic features, but optimization for production of electricity at a minimum cost has resulted in a number of significant changes in design.

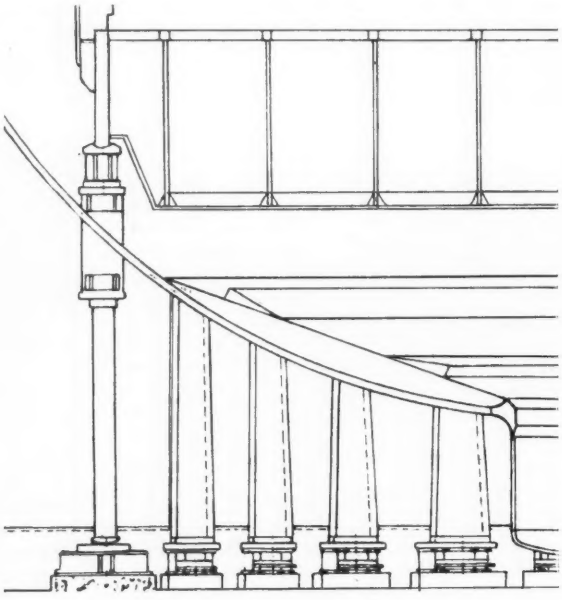


Chief amongst these occurs in the pressure vessel which to accommodate higher gas pressure and a larger reacting core—permitting not only a greater reactive volume but also, by flux flattening, a greater specific heat output—is spherical in shape, 66 ft. 6 in. inside diameter, and is fabricated from a newly-developed steel 3 in. in thickness. This steel has already completed a long period of testing and now fulfils the design requirements of low brittle/ductile transition temperature with low creep at high temperature. The effects of radiation exposures of the order of 10^{22} nvt corresponding to a reactor life of several tens of years are confidently expected to be negligible on present evidence. The steel is regarded as a natural follower to Lowtem, which was adopted for the Calder Hall pressure vessel.

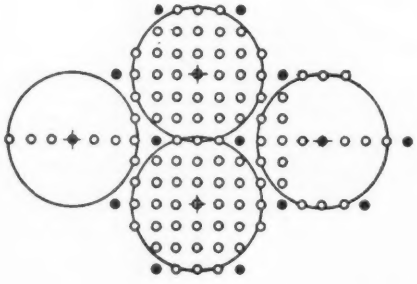
Of equal importance is the heat-transfer performance within the reactor core and in the boilers. On fuel elements it could be inferred from the discussion following the relevant paper delivered at the B.N.E.C. symposium that notable improvements have been made on the transverse helical fin discussed there. The close approach between reactor gas outlet temperature in the Bradwell reactors and the known safe operating temperature of the canning

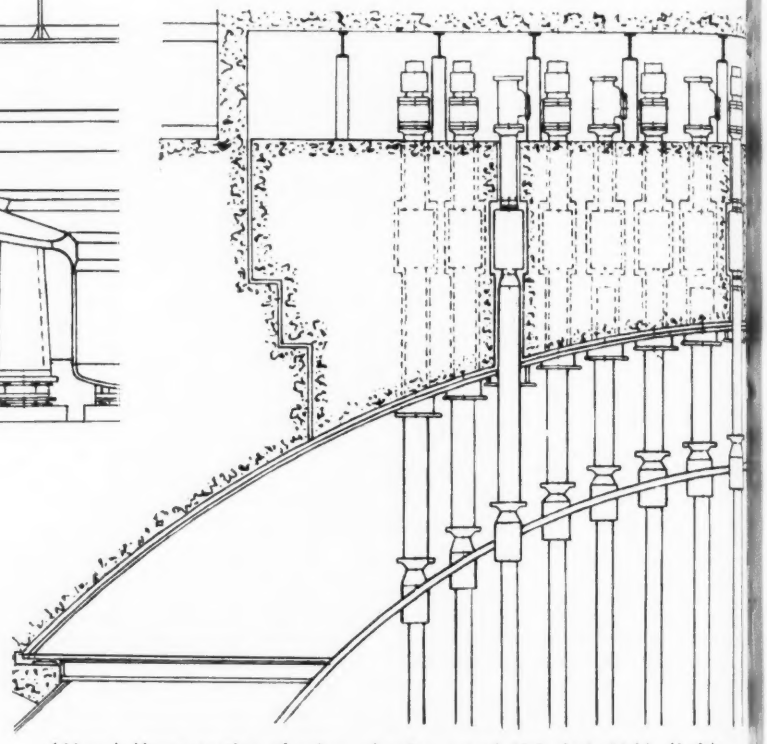
material bears this out. It is apparent also from the increased heat rating in the boilers, double the Calder figure, that great improvements have also been achieved there. Extensive use of Integron tubing and more efficient packing has brought this about.

The length of the fuel elements, 36 in., is substantially the same as at Calder Hall and the method of vertical stacking is retained. It is understood that some form of radial constraint of the elements is provided to prevent bowing during operation. A minimum burn-up time of 3,000 MW days/tonne is anticipated, and the limitations on this figure are expected to arise from metallurgical changes in the uranium rather than loss of reactivity.



Method of support of vessel.





(Above) Upper portion of sphere showing curved biological shield. (Left) Core lattice, showing operational radius of charge tubes.

The pressure vessel is supported on 24 frames, which can accommodate vessel expansion by a rolling action. The graphite is carried on ball bearings resting on flat plates which, in turn, are supported by a grid structure decreasing in depth towards the periphery. This grid is supported at the end of each member through rolling bearings by cylindrical columns which transmit the thrust from the end of each frame member directly through the vessel thickness to the legs.

An important feature of the design is the positioning of the boilers. These have been arranged in two groups of three to give minimum lateral spread in the layout and to ensure co-planar ductwork. Total enclosure of all boilers and ancillary pipes has minimized the dangers from frost and given a clean line to the reactor buildings. Several expansion joints are provided, the bellows being basically similar to those of Calder Hall. Instead, however, of the complex gimbal support which involved high bearing loads on the hinge pins, the single plane of movement allows the substitution of a flexible torque rod mounted inside the unit. The boilers have also been mounted as high as possible with respect to the reactor in order to ensure good circulation of the coolant by thermosyphoning in the event of circulator failure.

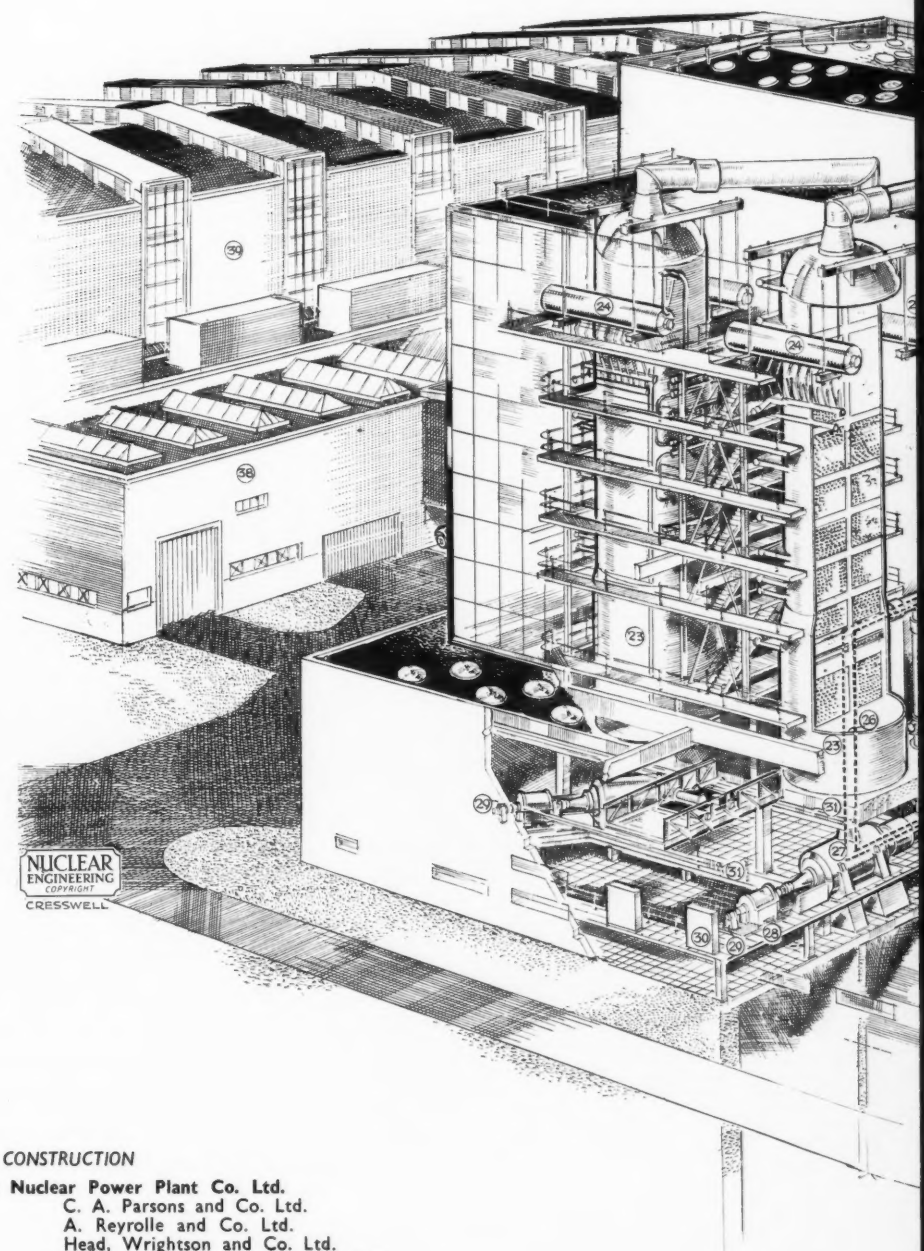
An axial flow circulator is mounted directly below each of the six boilers and exhausts into the cold "leg" of the duct circuit. The six circulators are driven by induction motors supplied from a steam turbo-alternator; control of the circulator speed is obtained by direct control of the turbine governor. In the Bradwell station three turbo-alternators are provided, one for each reactor and one as standby. The maximum output of these machines is 20.5 MW at full overspeed. The inertia of each circulator is increased by the addition of a flywheel. This will appreciably reduce the temperature reached by the fuel elements under fault conditions, particularly in the remote event of simultaneous failure of the circulators and the control system.

A by-pass is provided in each main duct circuit to allow each circulator to be run up and its associated boiler to be put into service with the reactor on load.

The charge and discharge machine is an integrated unit mounted on a gantry which runs on rails. Separate standpipes are provided for charging and control rods, each charging tube serving 37 fuel channels. Whilst the machine is remotely controlled, the operator can watch the machine through the window of a room on the charge floor. He can also see the functions inside the machine by closed-

The World's Reactors

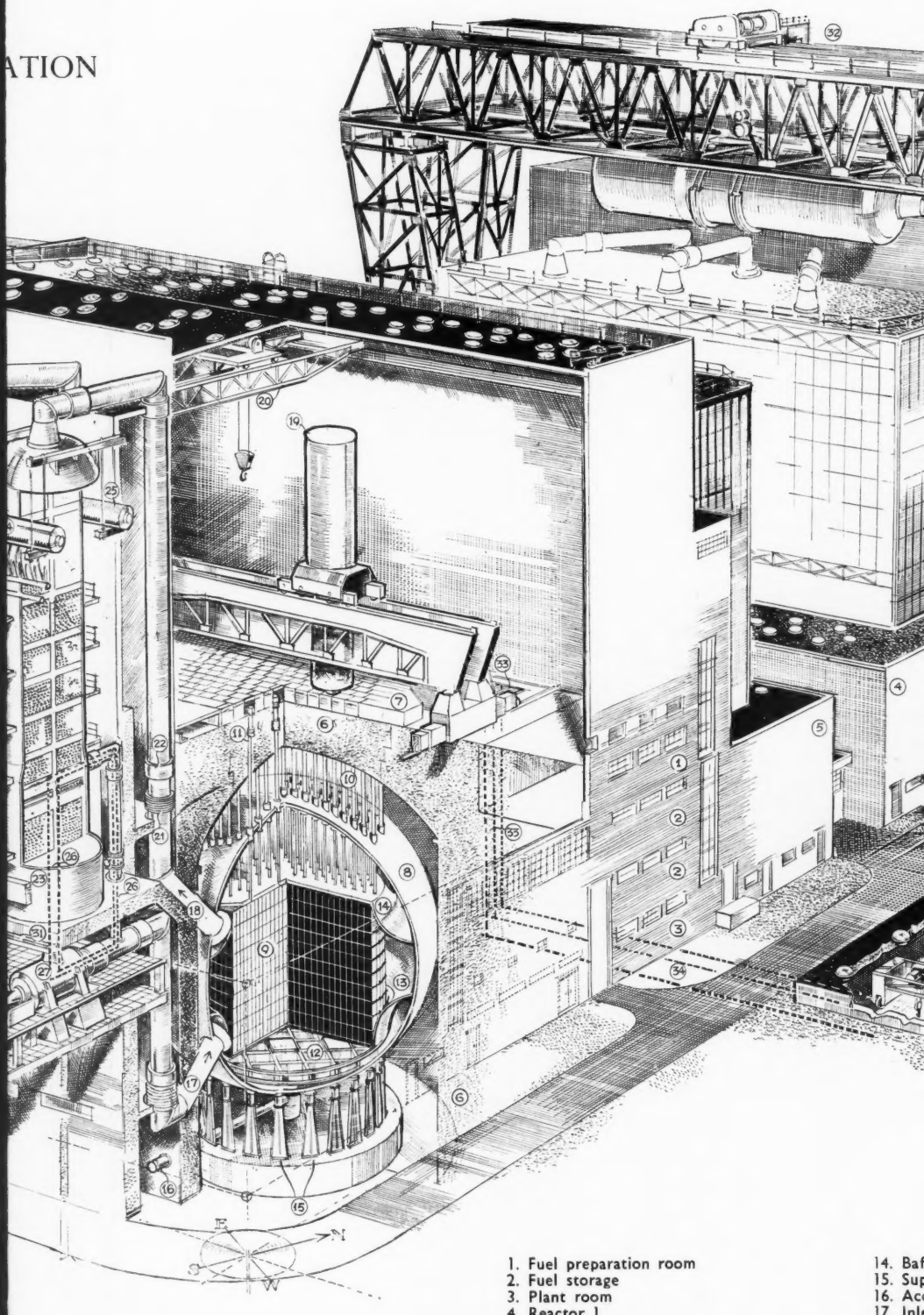
No. 11—BRADWELL-ON-SEA POWER STATION



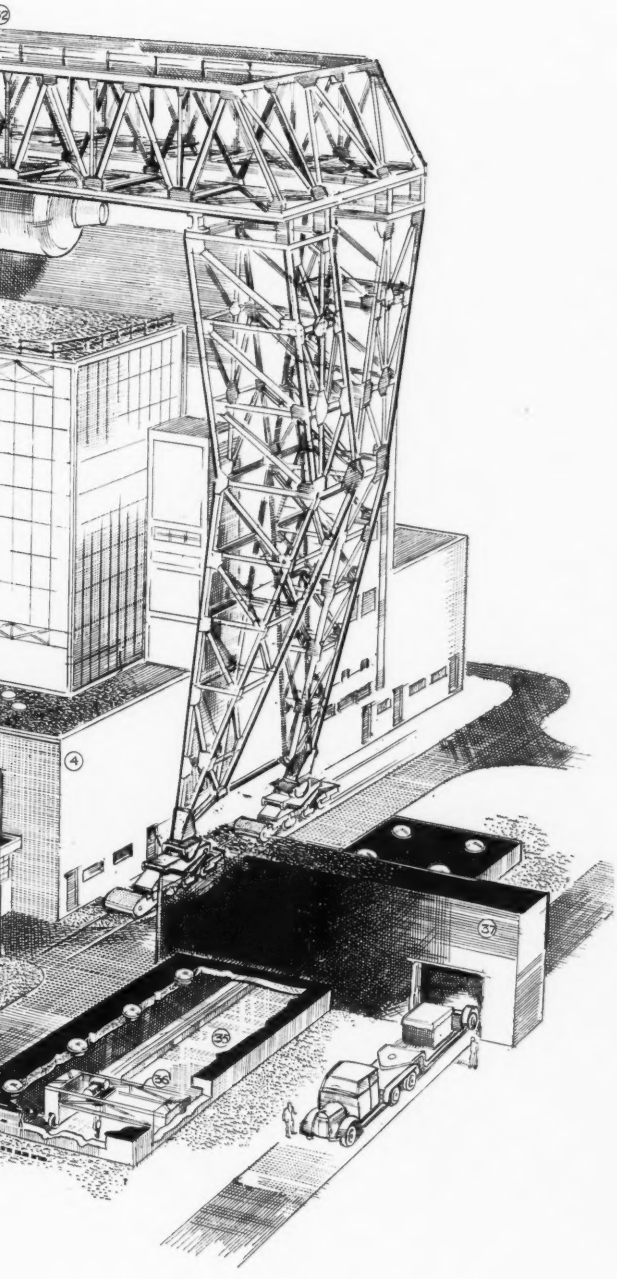
DESIGN AND CONSTRUCTION

The Nuclear Power Plant Co. Ltd.
C. A. Parsons and Co. Ltd.
A. Reyrolle and Co. Ltd.
Head, Wrightson and Co. Ltd.
Sir Robert McAlpine and Sons Ltd.
Whessoe Ltd.
Strachan and Henshaw Ltd.
Alex Findlay and Co. Ltd.
Clarke, Chapman and Co. Ltd.
Parolle Electrical Plant Co. Ltd.

ATION



1. Fuel preparation room
2. Fuel storage
3. Plant room
4. Reactor 1
5. Reactor 2
6. Biological shield
7. Secondary biological shield
8. Pressure vessel
9. Core
10. Charge standpipes
11. Control rod
12. Diagrid
13. Toroidal shield
14. Baf
15. Sup
16. Acc
17. Inl
18. Ou
19. Cha
20. 20-
21. Ma
22. Exp
23. Boi
24. L.P
25. H.P
26. By-



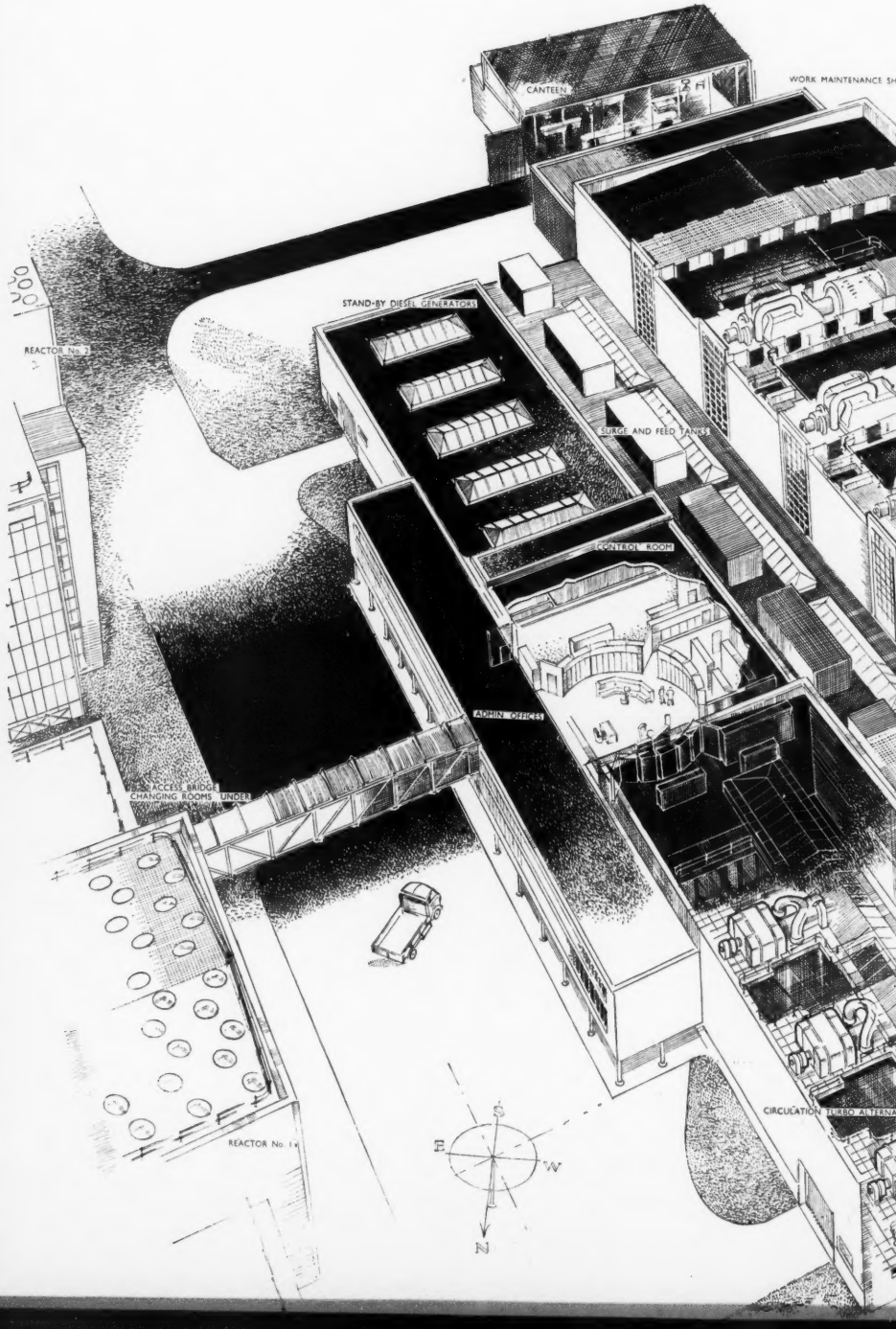
KEY

14. Baffle
15. Support frames
16. Access duct
17. Inlet duct
18. Outlet duct
19. Charge machine
20. 20-ton crane
21. Main duct valve
22. Expansion joint
23. Boiler
24. L.P. drum
25. H.P. drum
26. By-pass circuit
27. Main circulator
28. Circulator drive
29. Pony motor
30. Circulator control panel
31. Crane rails
32. Goliath crane
33. Discharge well
34. Disposal channel
35. Cooling pond
36. Pond crane
37. Loading bay
38. Auxiliary Diesels
39. Turbine house

The World's Reactors

No. 11—BRADWELL-ON-SEA POWER STATION

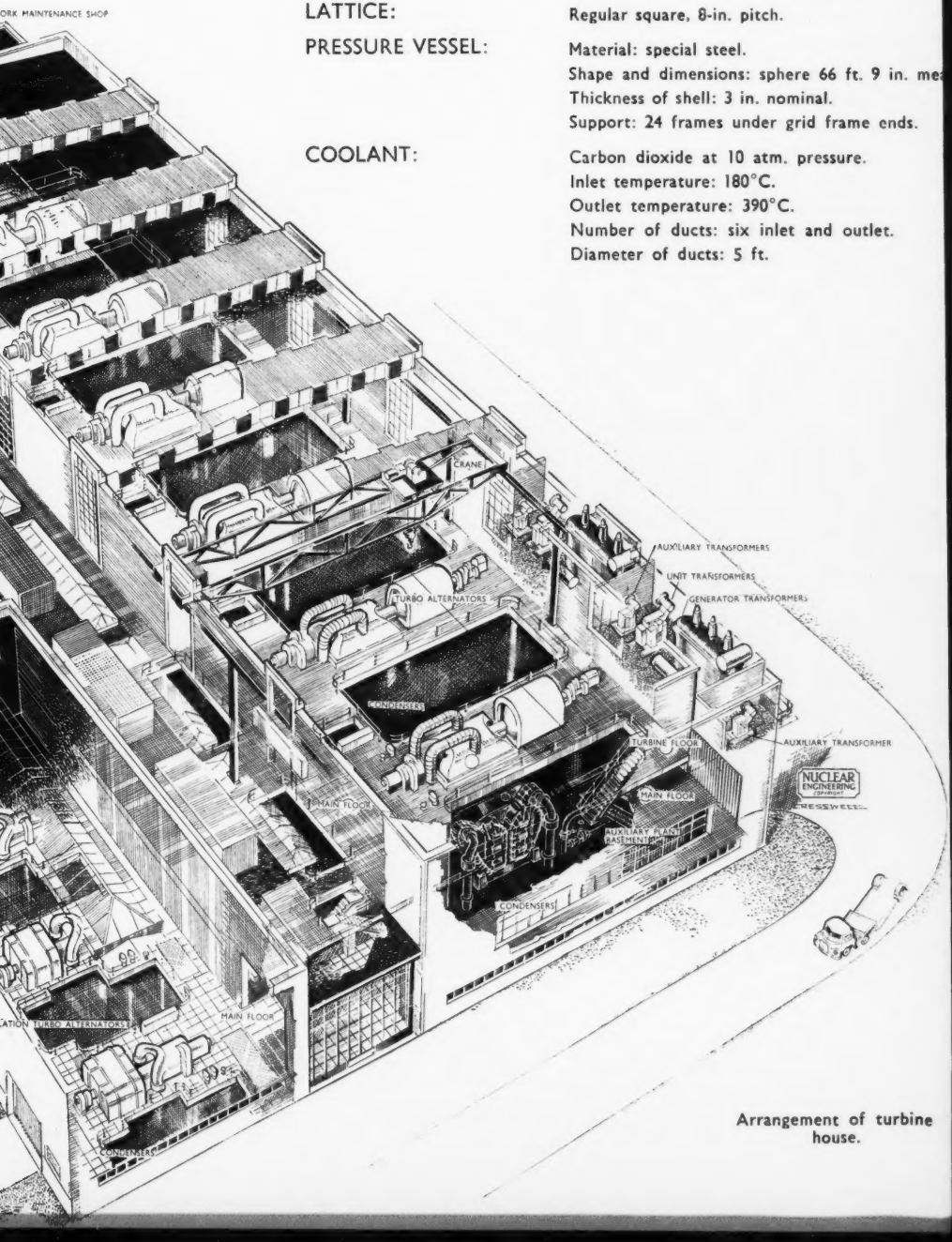
TYPE:	Thermal heterogeneous.
PURPOSE:	Power production.
LOCATION:	Bradwell-on-Sea, Essex.
OPERATION:	Ground broken: January 18, 1957. First reactor completed: mid-1960. Second reactor completed: end of 1960.
CAPACITY:	Station installed capacity: 328 MW+61 MW auxiliaries. Guaranteed net output: 300 MW. Reactor heat ratings: 530 MW.



TION

auxiliaries.

FUEL:	Material: natural uranium. Dimensions: 1.15 in. diameter, 36 in. long. Density: 18.7 g/cm^3. Weight of U per reactor: 240 tonnes. Number of elements per channel: eight. Number of fuel-element channels: 2,620. Diameter of channels: uniform through reac
CANNING:	Material: magnesium alloy, A.12. Construction: machined or extruded extend Method of element support: stacked.
MODERATOR:	Material: graphite. Core size: 40 ft. dia. × 25 ft. 8 in. high. Overall: 24-sided polygon, 45 ft. × 31 ft. Total weight per reactor: 1,910 tonnes. Method of support: ball bearings.
LATTICE:	Regular square, 8-in. pitch.
PRESSURE VESSEL:	Material: special steel. Shape and dimensions: sphere 66 ft. 9 in. me Thickness of shell: 3 in. nominal. Support: 24 frames under grid frame ends.
COOLANT:	Carbon dioxide at 10 atm. pressure. Inlet temperature: 180°C. Outlet temperature: 390°C. Number of ducts: six inlet and outlet. Diameter of ducts: 5 ft.



Arrangement of turbine house.

Material: natural uranium.
Dimensions: 1.15 in. diameter, 36 in. long.
Density: 18.7 g/cm^3.
Weight of U per reactor: 240 tonnes.
Number of elements per channel: eight.
Number of fuel-element channels: 2,620.
Diameter of channels: uniform through reactor.

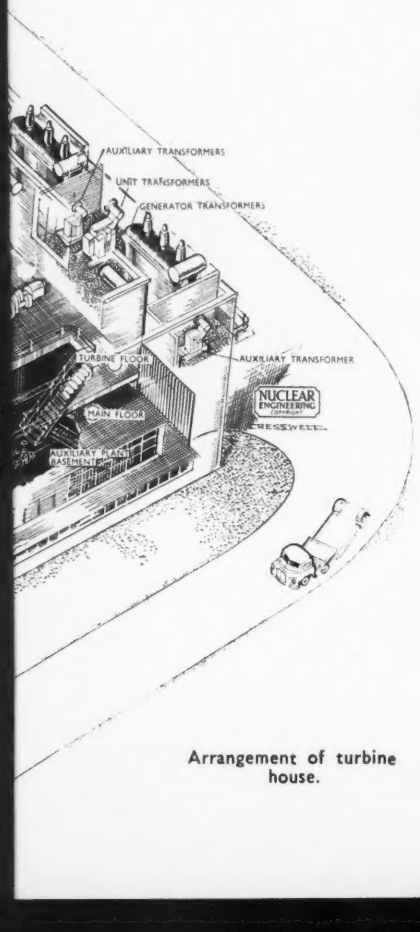
Material: magnesium alloy, A.12.
Construction: machined or extruded extended surface.
Method of element support: stacked.

Material: graphite.
Core size: 40 ft. dia. × 25 ft. 8 in. high.
Overall: 24-sided polygon, 45 ft. × 31 ft.
Total weight per reactor: 1,910 tonnes.
Method of support: ball bearings.

Regular square, 8-in. pitch.

Material: special steel.
Shape and dimensions: sphere 66 ft. 9 in. mean dia.
Thickness of shell: 3 in. nominal.
Support: 24 frames under grid frame ends.

Carbon dioxide at 10 atm. pressure.
Inlet temperature: 180°C.
Outlet temperature: 390°C.
Number of ducts: six inlet and outlet.
Diameter of ducts: 5 ft.



Arrangement of turbine house.

PUMPING: Number and typ
Drive: Variable alternator.
Running speed:
Turbo-alternator one turbo-alte

FLUX: Maximum therm
Method of flatte

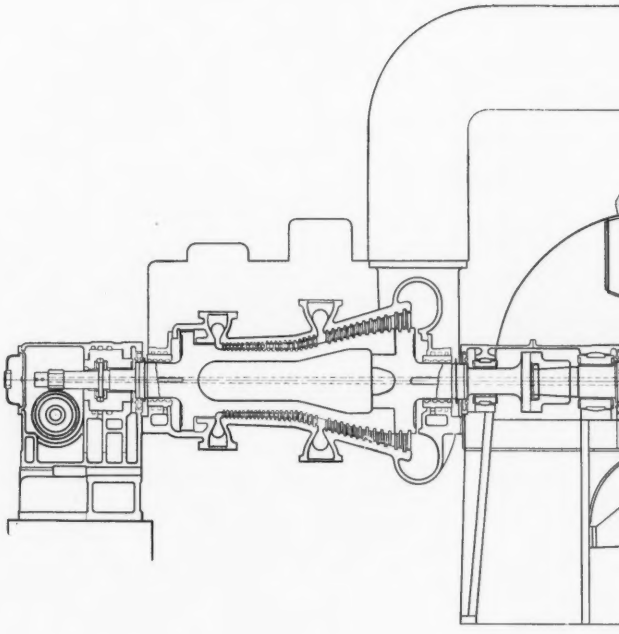
CONVERSION: 0.85.

BURN-UP: Minimum 3,000

REACTIVITY: Excess in cold,
Negative temper uranium: 2.3.1

CONTROL: Number of chan
Diameter: as fue
Control rods: 10
Shut-off: 12.
Drive: variable-f

SHIELDING: Biological: 9-10
Cooling: induce



Sectional view

BOILERS: Number per rea
Main shell dimen
Element constru
H.P. steam temp
H.P. steam press
L.P. steam temp
L.P. steam press

TURBO-ALTERNATORS: Number and ty
Maximum contin
Speed: 3,000 r.p
Generator volta
H.P. steam temp
H.P. steam pres
L.P. steam temp
L.P. steam pres
Maximum coolin

STEAM DUMPING: Station capacity

nber and type: six axial blowers.
e: Variable-frequency induction motors fed from turb
ternator.
ning speed: 600/3,300 r.p.m.
o-alternator power: 20.5 MW.
e turbo-alternator per station standby.

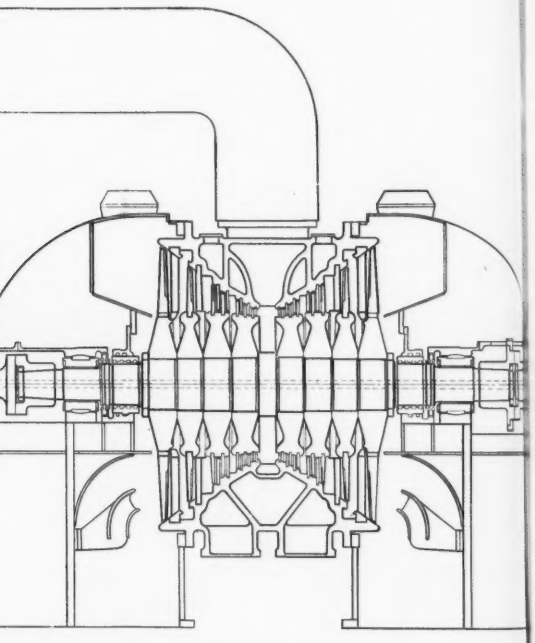
mum thermal neutron: $2.76.10^{13}$ n/cm^2-sec.
nod of flattening: steel rods in channels.

mum 3,000 MWD/tonne.

ss in cold, unpoisoned state: 4.9%.
tive temperature coefficient: moderator: $4.4.10^{-5}$/°C;
anium: $2.3.10^{-5}$/°C.

nber of channels per reactor: 120.
neter: as fuel elements.
trol rods: 108.
-off: 12.
e: variable-frequency induction motors.

ogical: 9-10 ft. concrete.
ling: induced draught, air.

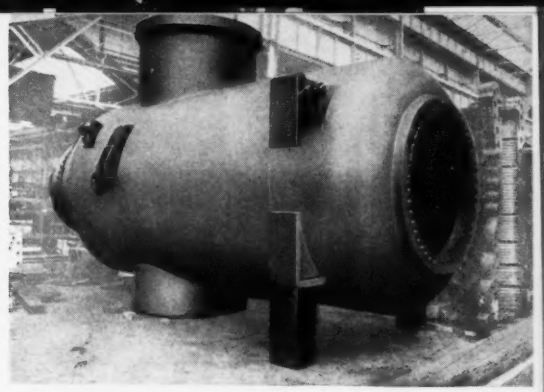


tional view of main turbine.

nber per reactor: six.
n shell dimensions: 19 ft. dia. × 87 ft. long.
nent construction: Integron finned tube.
steam temperature: 373°C (704°F).
steam pressure: 770 p.s.i.a.
steam temperature: 373°C (704°F).
steam pressure: 210 p.s.i.a.

nber and type: six impulse reaction.
imum continuous rating: 52 MW+5% margin.
ed: 3,000 r.p.m.
erator voltage: 11.8 kV.
steam temperature at T.S.V.: 371°C (700°F).
steam pressure at T.S.V.: 745 p.s.i.a.
steam temperature at T.S.V.: 371°C (700°F).
steam pressure at T.S.V.: 195 p.s.i.a.
imum cooling water temperature rise: 8.5°C (15°F).

ion capacity: 20% heat from each reactor.



Outer casing of axial blower

circuit television. Except that charging is to be carried out with the reactor on load, the sequence of operations has a marked resemblance to that at Calder Hall. The burst-slug detection gear "sniffing" pipes are brought up the control standpipes in which are mounted rotary selector valves. The total number of B.S.D.G. pipes, therefore, which need to be taken through the pressure wall is reduced considerably. The control rods, totalling 120 in number, include 12 which gang together and are used as shut-off rods. Drive for the rods is a refined version of the Calder Hall system, being based on a variable-frequency source feeding induction motors.

Although data on the proportions of high- and low-pressure steam are not available, it is significant that the high-pressure and low-pressure steam temperatures are the highest that have been quoted for the C.E.A. tenders. Temperatures at the turbine stop valves are both 700°F and the high-pressure and low-pressure are respectively 745 p.s.i.a. and 195 p.s.i.a. These conditions have only been exceeded so far in designs for liquid-metal-cooled reactors.

In the speed of construction of the station, the Goliath crane, with a height of 140 ft., a span of 167 ft. and a lifting capacity of 200 tons, will play a significant part. Spanning the complete station, it allows great flexibility in the constructional programme and eliminates the possibility of one section of the plant having to wait upon another for completion. The general order of construction will be similar to that adopted with Calder Hall, but somewhat greater use will be made of fabrication at the company's works.

From the outside the station will appear clean and compact and the very "tidiness" of the design gives some idea of the completeness of the integration of the design effort and the full consideration that has been given to the overall programming of the construction. The Bradwell site, whilst not as difficult from a waterlogged point of view as Berkeley, is less accessible and is remote from convenient labour pools.

La Centrale de Bradwell-on-Sea

La Nuclear Power Plant Co. Ltd. est en train de construire pour la Central Electricity Authority ce que l'on prétend être la première centrale nucléaire à produire de l'électricité à un prix économique. Le rendement net garanti est de 300 MW et la capacité totale de production installée de la centrale est de 390 MW. Les 90 MW supplémentaires servent en partie pour les auxiliares de la centrale et donnent aussi une marge permettant les augmentations du rendement du réacteur que auront lieu par la suite.

La conception du réacteur est basée sur le prototype de Calder Hall mais contient un certain nombre de changements fondamentaux. Une augmentation de la grandeur du noyau porte ce dernier à 12,4 m., et le diamètre est augmenté de 7,82 m. contenu dans un vaisseau à pression d'un diamètre intérieur de 20,3 m., fabriqué en un acier nouvellement développé d'une épaisseur de 3 in. (76 m/m). Le poids total du graphite est de 1.910 tonnes et le poids total de l'uranium par réacteur est de 240 tonnes. En tout, il y a 2.620 canalisations de combustible contenant en moyenne 8 éléments de combustible empilés par canalisation. La pression de fonctionnement du gaz acide carbonique est de 10 atmosphères.

Une grande attention a été dédiée lors de la conception au transfert de chaleur et une arête à surface augmentée considérablement améliorée a été dévelopée pour les éléments de combustible tandis que des tubes à arête Integron ont été adoptés pour les chaudières. Les chaudières, qui sont au nombre de six par réacteur possèdent environ le double du transfert de chaleur du type de Calder Hall.

Das Kraftwerk in Bradwell-on-Sea

Die Nuclear Power Plant Co. Ltd. baut z.Zt. für die C.E.A. (die staatliche Elektrizitäts Gesellschaft) ein Atom-Kraftwerk, das den Anspruch macht, das erste Atom-Kraftwerk zu sein, in dem Elektrizität zu einem wirtschaftlichen Preis erzeugt wird. Die garantierte Netto-Leistung ist 300 MW und die gesamte installierte Erzeugungs-Kapazität des Werks ist 390 MW. Die zusätzlichen 90 MW sind zum Teil dazu da, die Hilfsmaschinen und anderen Apparaturen des Werks zu versorgen, zum Teil dienen sie als Reserve, um spätere Erhöhung der Reaktor-Leistung zu gestatten. Die Konstruktion des Reaktors ist nach dem Muster von Calder Hall entwickelt worden, weist jedoch eine Anzahl von grundsätzlichen Aenderungen auf. Die Grösse des Kerns ist auf 12,4 m. Durchmesser gesteigert worden bei einer Höhe von 7,82 m. in einem Hochdruck-Behälter von 20,3 m. innerem Durchmesser, des aus Platten von 3 zoll Stärke aus einem neu entwickelten Stahl aufgebaut ist. Das gesamte Gewicht der Graphitmasse ist 1.910 t. (tonnes) und das gesamte Gewicht des Uraniums für jeden Reaktor 240 t. (tonnes). Insgesamt sind 2.620 Kanäle für den Brennstoff vorgesehen, die im Durchschnitt 8 Brennstoff-Patronen übereinander in jedem Kanal aufweisen. Der Betriebsdruck der Kohlensäure ist 10 Atm.

Grosser West ist auf die Konstruktion der Vorrichtungen zur Uebertragung der Wärme gelegt worden. Zu diesem Zweck ist eine wesentlich verbesserte Rippenanordnung mit vergrösserter Oberfläche für die Brennstoff-Patronen enwickelt worden, während für die Kessel "Integron" Rippen-Rohre verwendet werden. Die Kessel, von denen sechs auf jeden Reaktor kommen, haben angenähert die doppelte Wärme-Uebertragungsleistung der in Calder Hall verwendeten Type.

La Central de Bradwell-on-Sea

La Nuclear Power Co. Ltd. viene construyendo para la C.E.A. (Junta Central Eléctrica) lo que se cree ser la primera central de energía nuclear que produce electricidad a precios económicos. La capacidad neta guarantizada es de 300 MW y la capacidad total generadora instalada de la planta será de 390 MW. Estos 90 MW adicionales suministran en parte energía a las instalaciones auxiliares y también significan un margen que permitirá aumentar la capacidad posterior del reactor.

El diseño del reactor se base en el prototipo de Calder Hall, pero incluye ciertos cambios fundamentales. El tamaño del núcleo se aumenta a 12,4 m. de diámetro por 7,82 m. de altura y va contenido en un recipiente de presión de 20,3 m. diámetro interior, construido de un nuevo tipo de acero de tres pulgadas (76 mm.) de espesor. El peso total del grafito es de 1,910 toneladas y el peso total del uranio por reactor es de 240 toneladas. En total habrá 2.620 canales de combustible conteniendo un promedio de 8 elementos apilados de combustible por cada canal. La presión de funcionamiento del dióxido de carbón es de 10 atmósferas.

Se ha prestado atención especial al diseño de la transferencia de calor y se ha diseñado también una aleta de superficie notablemente mejorada para los elementos de combustible mientras que la tubería de aleta Integron ha sido adoptada para las calderas. Las calderas, de las que hay seis por cada reactor, tienen aproximadomente dos veces le transferencia de calor de las del tipo instalado en Calder Hall.

The Homogeneous Aqueous Reactor

by
I. WELLS, B.Sc., D.I.C., M.I.Chem.E.,
and D. NEWBY, B.Sc. (Eng.), A.M.I.Mech.E.
A.E.R.E., Harwell

In the annual report of the U.K.A.E.A. for 1955-56,[1] *it was stated that the Homogeneous Aqueous Reactor system was being studied as a stage-three reactor to attain much higher fuel utilization by means of breeding, and the work at present in progress at Harwell was described.*

HOMOGENEOUS aqueous systems employ fissile material in solution or suspension in light or heavy water as fuel. The water also acts as a moderator, and, in addition, if circulation of the fluid through a heat exchanger occurs, as a coolant. Since the coolant, moderator and fuel are an intimate mixture it is homogeneous. It is also, of course, a circulating fuel reactor, in which the fuel is continuously passed through the reactor, or core, and through the heat exchanger. This opens up the possibilities of continuously processing the fuel to remove fission products, thus preserving good neutron economy. Fertile material may be added to this circulating fluid (as in a single-zone system) or may be added to a second circulating circuit, part of which surrounds or blankets the core (a two-zone system) from which material further fissile material is bred. In the second case, that of a fertile blanket, a second processing plant removes the bred fissile material for feeding to the core. The homogeneous system is therefore an integrated system, and contains not only the reactor proper and its heat-removal circuits, but also the necessary chemical processing plants.

Fig. 1 shows in a simplified form a low-power single-zone reactor employing fissile material only. The fissile concentration is given for a bare unpoisoned system.[1] To achieve the steam pressures and temperatures required for power generation a pressurized system is necessary, and the pressure suggested in the figure is sufficient to prevent boiling even under conditions of power surge. The upper limit of reactor temperature is governed both by chemical considerations and pressure considerations, while the lower is set by the need to keep the steam pressure a maximum, and the pumping power a minimum with a reasonable size of heat exchanger. If a fertile blanket is added to such a reactor, a second heat-exchange circuit is required, since at equilibrium the fertile blanket will contain a quantity of fissile material, dependent upon the fissile removal rate by chemical processing. The fissile concentration required in the core will probably change in these circumstances.

Much of the attractiveness of the homogeneous aqueous reactor system derives from the fact that the solid metallic fuel elements are eliminated. Such elements have a limited burn-up, which requires a lengthy processing cycle to achieve greater utilization of the fissile material. The costs of such a process are high, and, moreover, the total inventory for the system is increased by reason of the fuel hold-up within the processing cycle. Parasitic absorption of the canning materials and structural parts in a heterogeneous system causes low neutron economy, and it is to the advantage of the H.A.R. that this absorption is very nearly eliminated.

The homogeneous aqueous systems, although most attractive from a reactor physics viewpoint, have their special structural and engineering problems, as well as providing the chemists and metallurgists with many problems in connection with corrosion. A later part of this article will discuss some of these problems and show that they are by no means insuperable. Before considering these problems, however, it is proposed to describe the system in rather greater detail, to show its advantages more fully, and to discuss the variations which are possible in the system. It is one of the advantages of the homogeneous system that it is flexible and may be employed in many different ways.

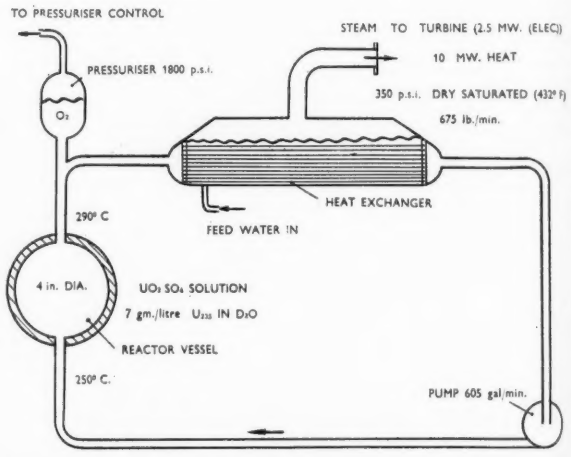


Fig. 1. Simplified diagram of low-power single-zone reactor.

Homogeneous Aqueous Reactor Fuel Cycles

The homogeneous aqueous systems can be used as burner, breeder or convertor reactors based on a thermal principle. Obviously a fast reactor is not possible because of the presence of a moderator, but epithermal systems may be feasible, although these have yet to be fully investigated.

In the *burner* reactor, pure or nearly pure fissile material is used, and this type is suitable usually for power production on a limited scale. Since neutron economy is of no account, in this case either light or heavy water may be used for the moderator and coolant. The use of natural uranium is impossible if light water is used as a moderator and coolant, since criticality cannot be achieved at any concentration or size. If heavy water is used instead, it is possible, but not practicable, since the minimum size of reactor[2] would be over 30 ft. in diameter with a uranium concentration of 80 g/l.

The *breeder* reactor contains, in addition to the fissile material, fertile material, which by neutron capture pro-

duces more fissile material of the same species as that consumed.

The *convertor* reactor produces fissile material of a different species, by using another fertile material. In both convertor and breeder reactors heavy water is used as moderator and coolant, since neutron economy is an important factor. The amount of material bred may be expressed in terms of a conversion factor (C), which is the ratio of the fissile atoms bred to the fissile atoms destroyed. In the case of breeder reactors, another term, gain factor (G), is sometimes used, and $G = C-1$. The valuable breeder reactor has a positive gain factor, but the breeder reactor class must also include those which have zero or slightly negative gain factors.

There are only three practical *fissile materials*, U 233, U 235 and Pu 239. The number of neutrons born per neutron absorbed (η) determines the usefulness from the breeding or conversion viewpoint. One of these neutrons is needed to sustain the chain reaction, while the remainder are available for breeding, parasitic capture and leakage, etc. The table of η values at 250°C shows that Pu 239 as a fissile material can never give a conversion factor greater than 1, since η is less than 2.

TABLE 1

Fissile material	U 233	U 235	Pu 239
η at 250°C	2.29	2.07	1.83

The two *fertile materials* available are U 238 and Th 232. These on neutron capture both suffer two β decays and produce Pu 239 and U 233 respectively. Thus it is possible to have breeder reactors employing either the Th 232 -U 233 cycle or the U 238-Pu 239 cycle. The former can have a positive gain factor, but the latter cannot, and must always have an additional external fissile source of supply available. If natural uranium be used as a feed material, the U 235 content represents this source of fissile material, and a positive gain factor of free fissile material may be achieved. To achieve this, however, depleted uranium will have to be rejected from the cycle. It is to be noted that there is no fertile material available from which U 235 may be bred in significant amounts. U 235 can therefore only be used in the conversion cycle.

Table 2 summarizes the information regarding fuel cycles for homogeneous reactors. This table assumes that, of the fissile materials, U 233 is the most valuable while Pu is of least value. This is a reasonable assumption if one remembers their η values. The only convertors of interest are, therefore, those which employ Th 232 as a fertile material. It is realized that the reactor employing U_{nat} as a feed and Pu as the main fissile material is not strictly a breeder system, since "bound" U 235 is present also. But, since in such a system, the majority of the Pu formed by neutron capture will derive from neutrons liberated by the fission of Pu, it is reasonable to call this system a breeder system. The U 233 burner has also been excluded, as it offers no advantage over the U 235 burner. Also shown in Table 2 are the conversion factors (in brackets) which may be expected from such systems. It should be noted that these are examples and are intended only to illustrate the trends which should obtain.

There remain, therefore, a number of systems, and the selection from these will depend upon their applications, the supply of fissile and fertile material and the type of fissile material which would be a valuable, saleable product. In a later article on the H.A.R. it is proposed to show how it is possible to use both convertor and breeder reactors to provide an expanding programme of electricity generation, if an annual supply of either U 235 or Pu is made available.

Types of Homogeneous Aqueous Reactor System

The *single-zone* system, Fig. 2 (a), eliminates the core container by using a mixture of fertile and fissile material in a single vessel. To achieve a reasonable conversion factor, a large vessel of about 13 ft. outside diameter is required because the neutron leakage is inherently greater than for a system with a fertile blanket. In addition, when operating on the U 233-thorium cycle, loss of neutrons by resonance capture in Pa 233 (the precursor of U 233), bred from the thorium, becomes more serious in the single-zone system. The resonance effect is flux-dependent, and in this system the fertile material is in the same high flux as the fissile material. Continuous removal of neutron poisons may also be effected in a single-zone system. This mixed system still has a negative temperature coefficient, but control of reactivity by adjustment of slurry concentration is not as easily achieved as fissile concentration in the core of a two-zone system. A higher fissile concentration is required, but more dilute slurries, around 500 g/l fertile material, can be used.

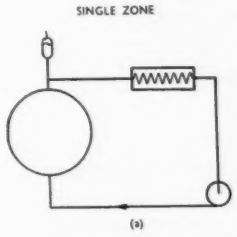


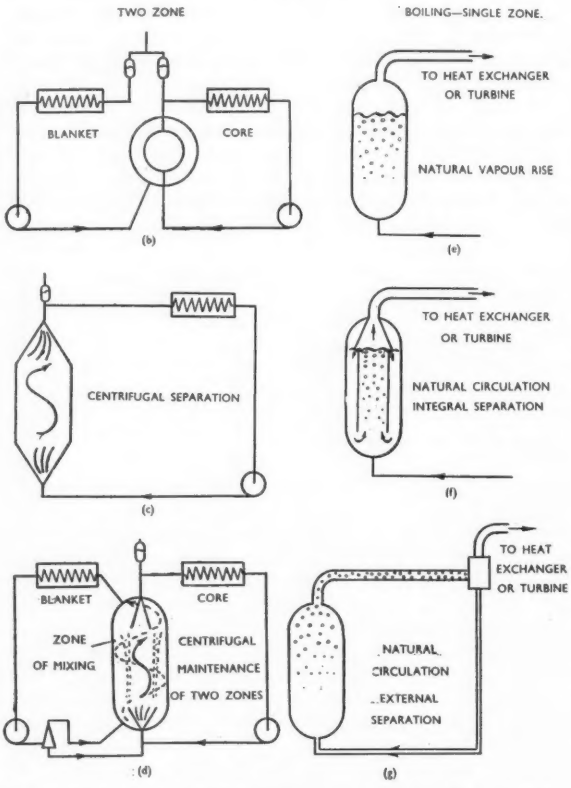
Fig. 2 (a). Single-zone reactor.

The *two-zone* system illustrated in Fig. 2 (b) has fissile material in the inner core, surrounded by fertile material in the outer blanket. A typical system would have a solution or suspension of 1 g/l fissile material in a core of 7 ft. diameter and a slurry or solution of 1,000 g/l fertile material in a blanket of 11 ft. outer diameter. Such a system in heavy water would have a good conversion factor and could be self-controlling above 100°C due to the negative temperature coefficient which arises mainly from the change in moderator density. Reactivity can be controlled by adjustment of the core fissile concentration, by evaporation or dilution of the solution. Fresh fissile material is produced in the blanket and, at a level of 0.3% fissile in the fertile material, about 30% of the total heat from the system comes from the blanket. Continuous fuel

TABLE 2—FUEL CYCLES IN HOMOGENEOUS AQUEOUS REACTOR SYSTEMS

Fertile material	—			Th 232			U_{nat}			U 238		
Fissile material	U 233	U 235	Pu	U 233	U 235	Pu	U 233	U 235	Pu	U 233	U 235	Pu
Single-zone systems	No advantage over U 235 burner	Burner (0)	Burner (0)	Breeder (1.0)	Convertor but isotopic separation required	Convertor (0.6)	Convertors, but end product less value than feed material		Breeder (0.9)	Convertors, but end product less value than feed material		Breeder (0.6)
Two-zone systems	One zone only required			Breeder (1.05)	Convertor (0.85)	Convertor (0.7)			Breeder (1.0)			Breeder (0.7)

processing should be capable of keeping the neutron poisons down to a low level. The core vessel must be neutron transparent and this limits the choice to the low cross-section metals zirconium, aluminium, magnesium, beryllium and silicon. The corrosion resistance of the materials tested has proved low and the search continues for an alloy or metal of suitable resistance.



Figs. 2 (b), (c) and (d). Two-zone reactors. Figs. 2 (e), (f) and (g). Single-zone boiling reactors.

Alternative methods of achieving a two-zone system without a metal barrier are shown in Fig. 2 (c) and 2 (d). In 2 (c) centrifugal force causes the dense fertile phase to separate to the outside and the light fuel phase to move to the centre. Unfortunately, the pressure drops required to achieve good separation are high and fuel is likely to become attached to the fertile material. System 2 (d), which handles the two phases in separate external circuits, would have a lower pressure drop.

Methods of Heat Removal

The reactor is normally pressurized to around 2,000 p.s.i. to prevent boiling and the heat removed by external circulation of the slurry or solution through heat exchangers as in Fig. 2 (b). In the two-zone system the external core circuit may be more than five times the core volume and the necessary increase in investment of fissile material is only tolerable because of the low fissile concentration. The external slurry blanket circuit is normally less than the blanket volume because of the lower heat rating of the blanket. In single-zone systems the higher fissile concentration required means that the external hold-up of fissile material becomes substantial and the tendency is to design compact circuits with high fluid velocities. Erosion rates with slurry systems are likely to put a limit on the permissible velocity.

Pressurizing problems can be removed, external hold-ups can be minimized and operating pressures reduced by allowing the solution to boil. With a *boiling reactor* all the heat can be removed at the maximum temperature obtainable in the reactor. Direct utilization of the steam in a turbine is doubtful because of the difficulty in decontaminating the steam to a sufficiently low level of activity. In addition, with heavy steam, the losses in the turbine plant are likely to be prohibitive in cost. The steam would therefore be used to generate secondary steam in a heat exchanger. The simplest boiling system is the natural vapour rise shown in Fig. 2 (e), but the rate of heat removal is governed by the free surface available. Excessive carry-over of moisture occurs as the heat removal increases. Better ratings can be achieved by the natural circulation-integral separation type shown in Fig. 2 (f), but in both these systems low-pressure drop steam separators are required for drying of the steam. The head available for steam separation can be improved by the natural circulation-external separation system of Alichanov[3] Fig. 2 (g).

The boiling system has other disadvantages. The reduced moderator density, due to boiling, increases the neutron leakage, and tends to reduce the conversion factor. Applying boiling to a two-zone reactor hardly seems practicable, but it is of interest to a single-zone system where fissile concentrations are high and minimizing the hold-up in the external circuit is necessary.

It is possible that either or both of the fuel and fertile circuits could be replaced by a *fluidized-bed* or a *packed-bed* system. Fluidized-bed systems would require a vessel of fairly regular shape and comparatively large particles of fissile (or fertile material) which did not break up by attrition or radiation. If it could be achieved it would reduce the material hold-up and largely eliminate the problem of circulating slurries. Packed beds have similar advantages but require much larger particles, and in this case there would be no mixing of the particles. As a result, the material will receive uneven radiation, the conversion factor would be reduced, and local heat generation may be large. Charging and discharging the reactor would not be as easy as in a fluidized system.

H.A.R. Basic Materials

The chemical compounds of interest for homogeneous aqueous systems are those containing uranium and plutonium for fissile materials and uranium and thorium for fertile materials. The requirement is that the compounds selected are stable and possess satisfactory properties over the range of operating characteristics of the reactor, i.e., ambient conditions to 300°C at 1,500 to 2,000 p.s.i. The elements in the compounds must also have a low parasitic capture cross-section.

Fissile Materials

Of the soluble salts of uranium, chlorides are not only highly corrosive but have objectionably high capture cross-sections and nitrates are unstable at elevated temperatures. Rather more complex compounds, such as oxyfluorides, phosphates, perchlorates and oxychlorides have been suggested, but uranyl sulphate (which has an acceptably low capture cross-section) appears to be the best soluble fuel. Much is known of its chemistry at elevated temperatures and pressures. Fig. 3 gives the phase diagram of the system UO_2SO_4-H_2O over the temperature range—60°C to 400°C.[4] Section A-B-C is the interesting portion of this diagram where two liquid phases can exist. On heating a uranyl sulphate solution, a second liquid phase separates out at temperatures above 300°C, the actual temperature depending upon the uranium concentration. For example, with a solution of 50 g/l U at 20°C (7.8% by weight of

UO_2SO_4), corresponding to line X-Y, the two-phase separation occurs at 310°C. At a concentration of 4 g/l U, phase separation does not take place until 340°C. The presence of excess acid increases the possible operating temperature.

Plutonyl sulphate is soluble to a limited extent at low temperatures in the presence of excess acid, but insufficient is known of the behaviour of this or of any other plutonium compound at elevated temperatures.

Slurry fuels are probably limited to the oxides of uranium and plutonium. The use of slurry fuels in the core of a two-zone reactor is likely to reduce the core vessel corrosion problems to those of a high-pressure water system unless stability requirements involves the use of corrosion-inducing additives. There is the problem of possible nuclear instability arising from the settling of a slurry fuel, and low settling rates are desirable. This is aided by the use of very fine particles and at the low solids content required (say, 10 g/l) it may be possible to prepare a suspension of particles fine enough to remain suspended by Brownian motion. Radiation must not cause growth of the particles in such a suspension. The use of the oxide UO_3 is doubtful because of the complicated chemistry of the system UO_3-H_20. About four hydrates exist, ranging from $UO_3.0.5H_2O$ to $UO_3.2H_2O$ and the stable hydrate depends upon the temperature. Slurries of these oxides are known to show a tendency to "caking" of the solid in dynamic circuits.[5] It is possible that by the use of a hydrogen atmosphere a slurry of the lower oxide UO_2 could be employed.[6]

Little is known about the behaviour of plutonium oxide.

Fertile Materials

The only fertile solutions of interest are those of uranyl or thorium nitrate and uranyl sulphate. The loss of neutrons to sulphate would seriously reduce the conversion factor when using a fuel of uranium-235 or plutonium. Nitrates are reported[4] to be unstable to the temperature required and to irradiation. In addition, nitrogen has a high absorption cross-section for thermal neutrons, and a high percentage of the neutrons being captured by the fertile nitrates would be lost. Neutron economy would require the use of separated nitrogen-15. This is only present in nitrogen to the extent of 0.37%. Separation would be sufficiently expensive on present knowledge to ensure that fertile nitrate solutions will not be used.

Possible *fertile slurries* are the oxides of uranium or thorium, but uranium oxides suffer from the disadvantages described in the previous section. Thorium dioxide is a very stable compound which does not form hydrates in high temperature water. Thorium dioxide slurries containing up to 10% by volume of solids (1,000 g/l) can be circulated and they appear to possess suitable physical and chemical stability under the proposed reactor conditions, but this has not been firmly established. The higher the concentration of fertile material, the thinner can be the blanket for a given conversion factor.

Heavy Water or Light Water

The cost of using light water can be assessed by considering the 10% (wt.) thoria slurry blanket of a two-zone system. For every 100 neutrons captured in a heavy-water slurry, only 0.4 are lost by capture in the heavy water. With a light-water slurry about 40 neutrons would be lost to the water, corresponding to a 40% loss of conversion factor which could only be compensated for by an increased usage of fissile material. Assume that a 400-MW heat reactor using 20 tonnes of heavy water in the slurry blanket is just self-sustaining. The fuel usage as thoria is insignificant, but if the heavy water costs £22,000[8] per tonne, an annual loss of 5% and an investment charge of 5% is equivalent to an operating cost of £120 per day.

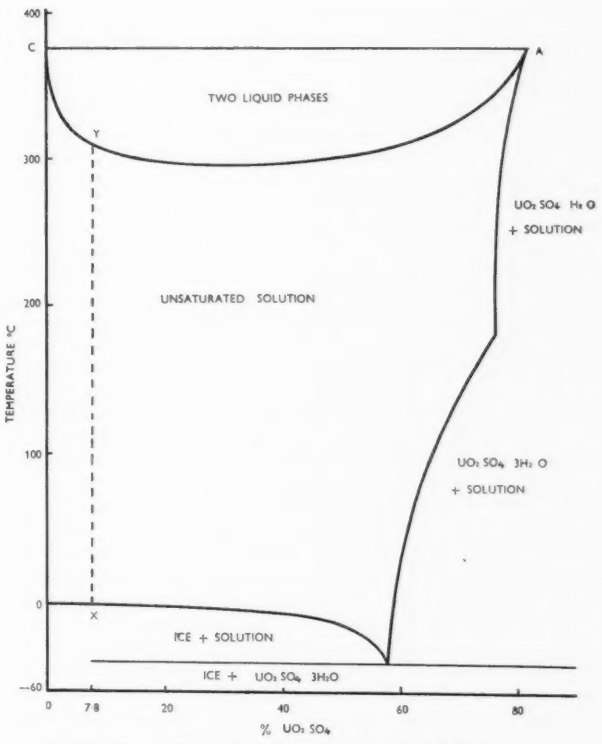


Fig. 3. Phase diagram for system uranyl sulphate-water.

Replacing the heavy water by light water saves these charges, but the 40% reduction in conversion factor necessitates a supply of fissile make-up material of about 160 g per day. At a fuel cost of £5/g,[9] this amounts to £800/day. Economically, therefore, there is a strong case for using heavy water in the blanket. With heavy water in the blanket, there are practical as well as nuclear advantages in having it in the core also.

Selection of a Reactor System

The choice of an advanced reactor system to be used in a large number of stations for electrical power generation can be made on the basis of the following criteria.

1. *Total cost of power kWh.* This is clearly of prime importance and consideration must be given to the effect of varying load factor.

2. *Capital cost/kW (elec.) installed.* In all probability, capital charges will be a controlling factor in determining the power costs, and the capital cost must be considered in relation to load factor and the rate of interest charged for capital. In this way this factor has been included in (1), but there will be many situations where the choice of a reactor system should fall on a reactor with minimum capital cost, even though the cost of power from the reactor may not be a minimum.

(3) *Inventory of fissile material kW (elec.).* This must be the total inventory of the system, and must include the fissile material within the reactor itself, and the hold-up in chemical processing, and fuel fabrication. The cost of this inventory will be included in item (1), but if there is an absolute shortage of fissile material, the inventory itself will govern the rate of annual growth of installed electrical capacity.

(4) *Materials utilization.* It has been argued that fertile material utilization must be high in order that the world's supply of natural fissile material is conserved. This is an

extremely long-range viewpoint and implies the desirability of developing a reactor with an effective conversion factor of at least unity. In the short term, this point must not be overstressed.

(5) *Reliability and maintenance.* The reliability of the reactor system must be assessed and this will include the amount and difficulty of preventive maintenance as well as the difficulties involved in actual maintenance and the probability of this being required.

(6) *Safety.* The safety of the system can be considered under two heads. One is the inherent safety which is present in a system, and concerns the "failure to safety" philosophy. The other concerns the effects of an incident, principally as it affects the surrounding countryside and population, and the necessity for containment.

(7) *Technologies and materials of construction.* Some assurance must be given that these will be available at the requisite time at a reasonable cost in terms both of money and scientific and technical man-power.

It will be noted that no mention has been made of thermal efficiency. It is contended that this is of no value in itself in comparing different reactor systems, except, perhaps, from the point of view of development potential. For any one system it does indeed affect the first four criteria, and thus it is included in the reckoning. But to compare system A with system B purely on the grounds of thermal efficiency (or what is, in effect, the basic parameter, the maximum operating temperature) is both inaccurate and incorrect. Thermal efficiency is legitimately used to compare different stations of the same class of system, as when comparisons are made between coal-fired stations, since the other factors involved are constant, or very nearly so.

The selection of a burner reactor must include other factors in addition to those discussed above, dependent upon the proposed location of the system, the difficulties of transport, both to and from the site, and the availability of cooling media. This class of reactor is essentially intended for electrical production in high-cost areas, and depends largely for its advantages upon the fact that bulky supplies of conventional fuels do not have to be supplied to the site. The system must also be capable of scaling down, enabling an electrical output as low as 5-10 MW to be obtained as economically as possible. In addition, in many locations it must be capable of economical operation at low load factors. This latter is, of course, a problem whenever reactor systems are considered, since, in general, of the total costs capital cost is a major item, while fuel cost is minor.

The Case for the H.A.R.

It is worth while applying the above process of selection and judgment to investigate the possibilities of the homogeneous aqueous system, taking first the two-zone breeder reactor operating on the Th-U 233 cycle, for use on a national basis for base load power generation.

The cost of power from such a system can only be approximately estimated at present, since accurate estimates of capital cost, which form a major part of the power cost, are not available. It is anticipated that both the cost of power generation and the capital cost/installed kW would be little different from those obtaining from other advanced reactor systems. One is reluctant to quote such estimates as have been made because of their approximate nature, but some guidance may be obtained from the Geneva Paper[7] by J. A. Lane, in which he quotes a capital cost of $256/kW (this figure does not include material inventories and processing plant costs), and a total power cost of 5 to 6 mills/kW can be inferred. It should be remembered that these American figures are subject to modification for British conditions, due particularly to the differing amortization charges and fissile material costs. Since the H.A.R. costs do not represent a striking reduction on the other advanced system costs, the selection of the H.A.R. for inclusion in a national generation programme cannot be justified on these bases. There is a reasonable assurance that fuel costs need not exceed 0.1d/kWh and could well be less.

It is when one considers the next two criteria that the real advantages of the system are seen. The overall fissile material inventory may well prove to be the lowest of any known system, and should not exceed 1 kg/MW (elec.), including the hold-up in core and blanket circuits and in both the integral processing plants and the thoria processing plants. The conversion factor of the two-zone reactors is high for a thermal system, and should exceed unity by a few per cent. This is due to the fact that fission product poisons are kept at a low level by continuous chemical processing; the moderator, heavy water, combines negligible capture with good moderating properties; and the homogeneous nature of the reactor eliminates the need for large amounts of structural materials (such as fuel rod cans) within the reactor. No other system has these advantages in such measure, as they are inherent to the homogeneous nature of the system coupled with the use of heavy water as moderator and coolant.

If the reactor is examined on the grounds of reliability, it is seen that the main weakness of the system is probably in the main circulating pumps and heat exchangers. Much can be done by care in design and manufacture and by pre-testing to assure reliability which, however, can only be proven in practice. The operational pressures required are no inherent drawback to the reliability of the system, but they do entail very highly skilled design and manufacturing practice.

The safety of the system suffers from the apparent disadvantage of having a very highly active fluid circulating at high temperature and pressure. However, the large negative temperature coefficient is sufficient for control of the reactor and no control rods or shut-off rods are proposed for such a system. Control of the operational temperature is by solution concentration and the power output is self-regulating to power demand from the secondary side of the heat exchangers. This large negative temperature coefficient provides inherent nuclear safety above 100°C, and run-away is believed to be impossible in such a system. Large increases of reactivity do lead to large power surges, but their duration is of the order of milliseconds and the integrated power appears to be small. The mechanical safety of the system can be ensured by correct design and selection of materials. However, it is generally accepted that in this type of system which employs circulating fuel the reactor should be contained in a leak-tight containment vessel. Such a vessel would, in the event of a major failure of the primary circuits, enable the effects to be localized and dealt with at a convenient time. Summarizing, it can be said that the reactor is inherently safe nuclearwise, it can be made so mechanically and, in any event, the effects can be contained.

The availability of technologies and materials of construction is the point at which some of the problems of the H.A.R. emerge. The system is an advanced system and any of the advanced systems suffer from similar problems. But, given the necessary effort, there is no fundamental obstacle to their solution. It is proposed to discuss these in detail in a subsequent article and here it suffices to list the major problems requiring development effort.

(1) The technology of slurries.

Le Réacteur Aqueux Homogène

Ce système emploie des matières fissiles et fertiles sous forme de solutions, suspensions et boues que l'on fait circuler dans le réacteur proprement dit et les circuits d'élimination de chaleur. Le système peut être employé en tant que réacteur brûleur, convertisseur ou éleveur, et ces systèmes peuvent être soit à zone unique ou à double zone, pressurisés, ou des systèmes à ébullition. La matière fissile, si c'est de l'uranium, est préférablement un solution de sulfate d'uranyle, tandis que la matière fertile peut être une boue de l'oxyde. De l'eau légère ou lourde pourra être employée comme modérateur ou réfrigérant.

Il est considéré comme établi que le choix d'un système de réacteur pour la production nationale de l'énergie ne dépend pas directement du rendement thermique. On montre que le réacteur éleveur homogène a l'avantage d'un inventaire réduit de la matière fissile, allié à un bon facteur de conversion lui permettant de se soutenir lui-même par une alimentation en thorium lors de son emploi sur le cycle Th 232-U 233. Le réacteur brûleur homogène possède l'advantage de la simplicité de l'actionnement et ne nécessite pas le transport d'éléments combustibles irradiés d'endroits éloignés.

Der homogene Reaktor mit flüssigem Kern

Dieses System arbeitet mit spaltbaren Stoffen und mit Brutstoffen in Form von Lösungen, Suspensionen und Aufschlämmungen, die durch den eigentlichen Reaktor hindurch und in den die Wärme aufnehmenden Kreisen in Umlauf gebracht werden. Das System kann als Reaktor mit Verbrennung des Brennstoffes, als Stoffwandler und als Brut-Reaktor arbeiten; in den verschiedenen Formen kann es mit einer Druckzone oder mit zwei Druckzonen versehen sein, oder es kann zu den "kochenden" Systemen gehören. Als Spaltmaterial wird zweckmässig eine Uranyl-Sulphat-Lösung gewählt, falls mit Uran gearbeitet wird, während als Brutsoff eine Aufschlämmung des Oxyds benutzt werden kann. Als Bremsstoff und Kühlmittel kann leichtes oder schweres Wasser dienen.

Es wird als Grundsatz aufgestellt, dass die Wahl des Reaktor-Systems nicht direkt von wärmewirtschaftlichen Ueberlegungen abhänging ist. Es wird gezeigt, dass der homogene Brut-Reaktor den Vorteil hat, dass mit geringen Mengen von Spaltstoffen begonnen werden kann, wobei ein guter Umwandlungs-Faktor es gestattet, dass der Reaktor sich selbst erhält mit einer Zufuhr von Thorium im Kreislauf Th 232-U 233. Der homogene Verbrennungs-Reaktor hat den Vorteil der Einfachheit der Kontrolle und verlangt ferner nicht den Transport von bestrahlten Brennstoff-Patronen von entfernter gelegenen Lagern.

El Reactor Acuoso Homogéneo

Este sistema emplea materiales fisionables y fertiles en la forma de solucione, suspensiones y pastas aguadas que se hacen circular a través del reactor mismo y de los circuitos de eliminación del calor. El sistema puede ser empleado como un reactor quemador, convertidor o criador, y estos sistemas pueden ser o bien de una sola zona o de dos zonas sobrecargadas, o sistemas a ebullición. La materia fisionable, si es uranio, es preferiblemente una solución de sulfato de uranilo, mientras que la materia fertil puede ser una lechada o pasta aguada del óxido. Se pueden emplear ya sea agua ligera o agua pesada como el moderador o refrigerante.

Se considera que la selección de un sistema de reactor para la generación de energia sobre una base nacional no depende directamente de eficiencia térmica. Se muestra que el reactor criador homogéneo tiene la ventaja de un inventario bajo de materia fisionable, conjuntamente con un buen factor de conversión que permite que se sostenga por sí mismo con una alimentación de torio al ser empleado en el ciclo Th 232-U 233. El reactor quemador homogéneo tiene la ventaja de facilidad de control y no exige la transportación de los elementos irradiados de combustible de sitios remotos.

(2) The development of a suitable neutron-transparent corrosion-resistant core vessel material.

(3) The development of reliable components.

(4) The development of remote maintenance techniques.

The *single-zone system* eliminates one of the principal problems of the two-zone system, that of the core vessel material corrosion. At the same time, however, it also eliminates one of the principal advantages of the system, as the fissile investment is increased by a factor of $2\frac{1}{2}$ to 3 times, thus bringing it within the range of other reactors. In addition, the conversion factor is lowered, and it is probable that a conversion factor of one will only just be obtained even if a much larger sphere is used. It is thus difficult to justify the development of a single-zone H.A.R. breeder reactor employing the Th 232-U 233 cycle.

The homogeneous system applied to *burner reactors* offers many unique advantages. In such a reactor it is envisaged that there would be no depoisoning or gas removal. It should run for up to 20 years without removing the fuel charge, and would only require a regular make-up of fissile material to replace that consumed. The costs of power from such a system depend very much on its location and the ease of transport of materials. In remote areas the H.A.R. burner gains from the fact that it does not require irradiated fuel elements, which have to be contained in shielded coffins weighing many tons, to be transported back to a central processing plant. A natural-uranium heterogeneous system, in which the irradiated fuel elements are stored at the reactor site, would remove this difficulty, and this may be found to be economically attractive. Where skilled operating manpower is at a premium, it is an advantage that the homogeneous burner, once started, may be controlled by the turbine throttle valve only. It is estimated that the system would, at periods of zero electrical load, not be shut down, but idle at temperature at very low power, a procedure peculiarly suitable to the H.A.R. system. Complete shutdown would be required for scheduled maintenance, but it is to be hoped that this would be kept at a minimum. A disadvantage of the H.A.R. system in such an application is the need for cooling water for the turbine condensers; a system which can use a gas turbine which requires no cooling water is at an advantage here. The burner system removes two of the problems outstanding in the two-zone breeder system, and in this respect it may be nearer in time. Problems of slurry technologies do not exist, since there will be no fertile materials present, and the core vessel material problem is removed.

It is proposed in *Nuclear Engineering*, 2, June, to describe some of the major problems of homogeneous systems and the manner and means of their solution. An example of a possible two-zone system will be described in greater detail, together with a further description of a single-zone system. There have been two experimental homogeneous systems built, and these, together with power systems proposed in the U.S.A., will be discussed.

REFERENCES

[1] Annual Report of the United Kingdom Atomic Energy Authority, 1955-1956. (H.M.S.O.)

[2] *Reactor Handbook*, Engineering Volume. Chapter 4.2. (U.S.A.E.C.)

[3] Alichanov, A. I., *et al.* International Conference on the Peaceful Uses of Atomic Energy, Geneva, August, 1955. Paper 624, "A Boiling Homogeneous Reactor for Power".

[4] Secoy, C. H. Ibid, Paper 821, "Survey of Homogeneous Reactor Chemical Problems".

[5] Kitzes, A. S., and Lyon, R. N. Ibid, Paper 811, "Aqueous Uranium and Thorium Slurries".

[6] de Bruyn, H., *et al.* Ibid, Paper 936, "Homogeneous Oxide Suspension Reactor".

[7] Lane, J. A. Ibid, Paper 476. "Economics of the Nuclear Power".

[8] U.S.A.E.C. Press Release 795, March 13, 1956.

[9] Jukes, J. A. Talk to West of England Fuel and Power Conference at Bristol, October 23, 1956.

Physical Society Exhibition

Many items of interest to the nuclear engineer were included amongst the display of instruments and equipment at the Old and New Halls of the Royal Horticultural Society, Westminster, London, from March 25 to 28.

ACCLES AND POLLOCK LTD.,
Oldbury, Birmingham.

Tubes in special metals. Tantalum, beryllium, vanadium, molybdenum, niobium, zirconium and titanium.

Helically-finned steel tubing. Surface-to-area ratios in excess of 2½:1 have been obtained in steel: experiments are proceeding to obtain a deeper fin in relation to the overall diameter of the tubing.

AUTOMATIC COIL WINDER AND ELECTRICAL EQUIPMENT CO. LTD.,
92-96 Vauxhall Bridge Road, London, S.W.1.

Avo portable D.C. amplifier. A highly-stable amplifier for measuring the minute currents produced in ionization chambers.

Avo radiac survey meters, Marks 2 and 3. Compact sealed instruments for use by personnel engaged upon the detection and measurement of gamma or beta radiation.

Sensitive radiation monitor. Capable of measuring both beta and gamma radiation.

BAIRD AND TATLOCK (LONDON) LTD.,
14-17 St. Cross Street, London, E.C.1.

Analmatic uranium analyser. In uranium refining the ion-exchange process is now extensively used, the uranium being separated by adsorption in a resin column and subsequently removed by elution. The Analmatic offers rapid and continuous chemical analysis of the column effluents.

BALDWIN INSTRUMENTS CO. LTD.,
Brooklands Works, Dartford, Kent.

Atomat transverse profiler. A new type of beta gauge for measuring weight per unit area of paper or plastic samples.

Various thickness gauges. Beta-ray gauge for sheet or strip with automatic standardization feature. Gauge for use on cold strip rolling-mill. Tube wall thickness gauge.

Nucleonic level indicator. When material in a container cuts a radioactive beam the level of the contents can be indicated.

BURNDEPT LTD.,
West Street, Erith, Kent.

Fast neutron monitor (1407*C*). Employs proton recoil proportional counter. Three count ranges—0-4, 0-40 and 0-400. Battery-powered and self-contained in sealed case. 16 in. by 10 in. by 6 in. Developed for A.E.R.E., Harwell.

Transistorized geiger counter (*B.N.*113). Small portable survey ratemeter. Full-sized geiger tube. Transistors temperature-compensated. Power provided by three Leclanché or mercury cells. Two-range meter and headphones.

COSSOR INSTRUMENTS LTD.,
Cossor House, Highbury Grove, London, N.5.

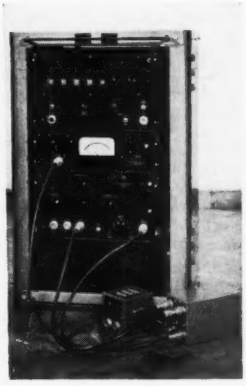
Ultrasonic test set (1064). For measuring weld flaws in pipelines and similar structures under site conditions. Single, dual or combined T and R probes. Mains operated, weight 42 lb.

DYNATRON RADIO LTD.,
Castle Hill, Maidenhead, Berks.

Single-channel-scanning pulse-amplitude analyser. Accepts pulses in the range 5 to 110 V and transmits those pulses whose amplitudes lie within selected levels.

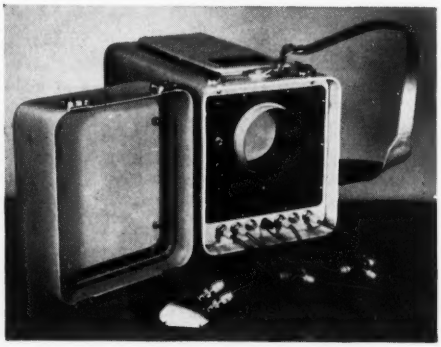
Transistor-operated portable scaling unit (1287*A*). Portable decade scaler designed for field use. Independent of mains supply. With the addition of a suitable G-M tube, the equipment is suitable for the detection and measurement of radioactivity.

(Above) Portable D.C. amplifier (1388A). **Automatic Coil Winder and Electrical Equipment Co. Ltd.**



(Right) Counting equipment (127), showing head amplifier and probe unit. **Ericsson Telephones Ltd.**

(Below) Ultrasonic test set. **Cossor Instruments Ltd.**



ELLIOTT BROS (LONDON) LTD.,
Century Works, Lewisham, London, S.E.13.

Analogue computer (*G-PAC*). A real-time D.C. analogue computer capable of handling a wide range of linear and non-linear problems.

E.M.I. ELECTRONICS LTD.,
Hayes, Middlesex.

Pulse generator, type 2. Produces a variable-duration pulse with a time of rise of 10 mμ/sec by means of a secondary emission pentode, the pulse duration being determined by a delay line.

Photomultiplier tubes. The sensitive surface is on the inner face of a flat window which forms the end of the envelope. Photoelectrons from the surface are multiplied in a system of sensitized surfaces having 11, 13 or 14 dynodes.

EKCO ELECTRONICS LTD.,
Ekco Works, Southend-on-Sea, Essex.

Scintillation counter (*N550A*). With a well-crystal (N597) and scaler (N530) this equipment forms a complete automatic counting unit for the assay of very low activity gamma-emitting sources.

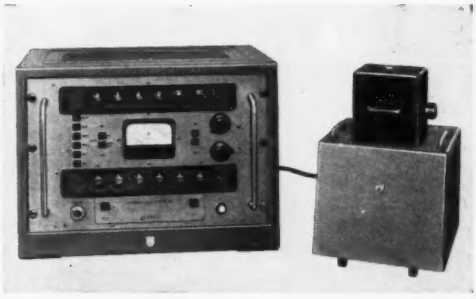
Beta scintillation counter (*N*612). For counting low-energy beta particles; particularly useful for the assay of ^{14}C and tritium. If the active material is not soluble in liquid phosphor, it may be suspended in a scintillating gel.

Profiler (*N*602). Nucleonic substance gauge for measuring the transverse of paper or plastic sheet. Two pre-set scanning speeds; thickness profile indicated and recorded.

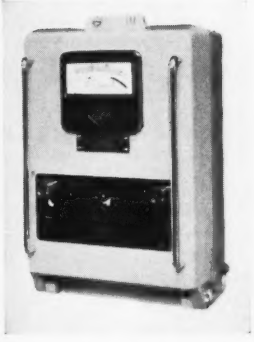
Gamma gauge for measuring fluid density (*N*611). The absorption of gamma radiation in a liquid is used to measure the specific gravity of the liquid. Changes in density of 0.005 can be recorded.

(Above) Survey meter (125). **Ericsson Telephones Ltd.**

(Below) Transistorized Geiger counter (BN113). **Burndept Ltd.**

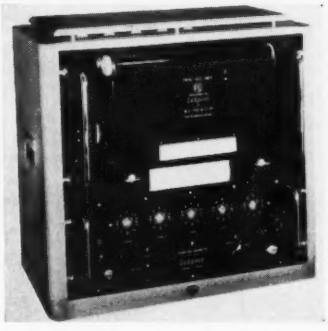


(Above) Automatic scaler (N530) with scintillation counter (N550A). **Ekco Electronics Ltd.**

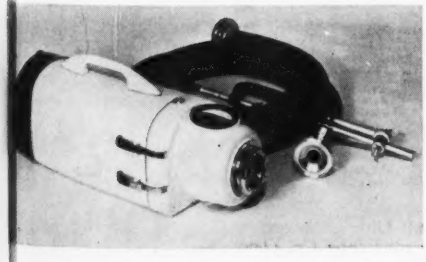


(Above) Nucleonics level indicator. **Baldwin Instruments Co. Ltd.**

(Below) Printing counter (D4123) with print-out unit. **Labgear (Cambridge) Ltd.**

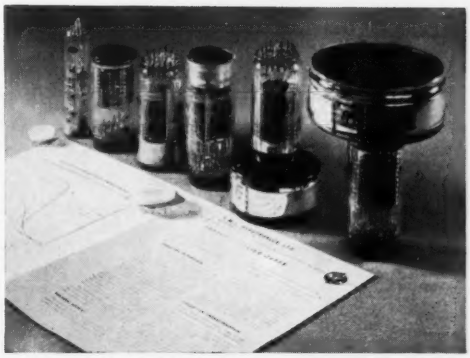


(Above) Castle (1355B) for measuring beta activity. **Fleming Radio (Developments) Ltd.**



(Left) Dust sampling unit (1355B). **Fleming Radio (Developments) Ltd.**

(Right) Range of photomultiplier tubes. **E.M.I. Electronics Ltd.**



ERICSSON TELEPHONES LTD.,
High Church Street, New Basford, Nottingham.

Counting equipment (127). Similar to the 1357 scaling unit developed in conjunction with the A.E.R.E. Comprises a pre-amplifier, an amplifier discriminator, a scaling unit, an E.H.T. unit and a power unit.

Field ratemeter (125). Lightweight pocket instrument intended for geological surveying and prospecting for radioactive ores. Circuit includes two transistors.

Bi-directional register (135). Maximum count 10^6. Addition and subtraction facilities. Two input channels with dekatron circuits. Maximum repetition rate 100 pulses per second.

Summation unit (132). For feeding impulses from several separate channels into one counting or scaling instrument.

ISOTOPE DEVELOPMENTS LTD.,
Beenham Grange, Aldermaston Wharf, Reading, Berks.

Gamma reflection gauge (190). For thickness measurement in the range 200 mg/cm^2 to 2,000 mg/cm^2. Novel collimation, self-calibration and radiation protection features. Overall accuracy to $\pm 1\%$.

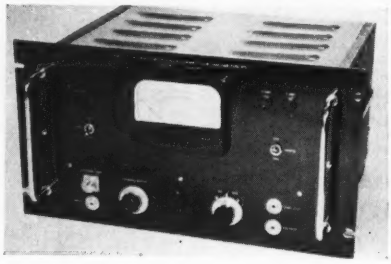
Experimental profile gauge. Continuous measurement and recording of profile of continuously extruded rod or tube, using beta-ray shadow method. Measurement independent of transverse movement to $\pm \frac{1}{4}$ in.

Ionization chamber (1506*B*). General-purpose health monitor. A large gamma ionization chamber with air-wall characteristics. It operates at atmospheric pressure and delivers a current of 6×10^{-12} A at a dose rate of 10 mr/hr.

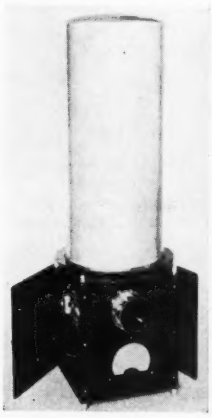
Single-channel pulse analyser (162) *with automatic scanning unit* (701). Automatic plotting of pulse height spectra. General-purpose unit with channel-width stability of better than 2% and a paralysis time of less than 2.5 microseconds. Operated in conjunction with the automatic scanner.

KELVIN AND HUGHES LTD.,
New North Road, Barkingside, Essex.

Selection of new instrument motors. Precision-governed and

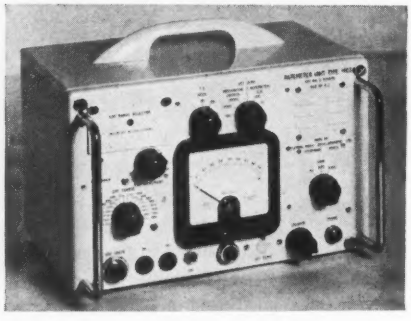


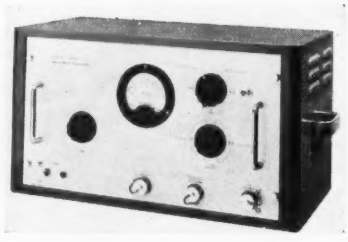
(Left) Single - channel pulse analyser (672). **Isotope Developments Ltd.**



(Above) Large gamma - ionization chamber for health monitoring **Isotope Developments Ltd.**

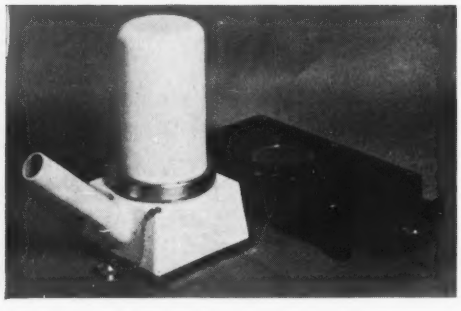
(Below) Universal scaler-ratemeter unit (1403A). **Fleming Radio (Developments) Ltd.**

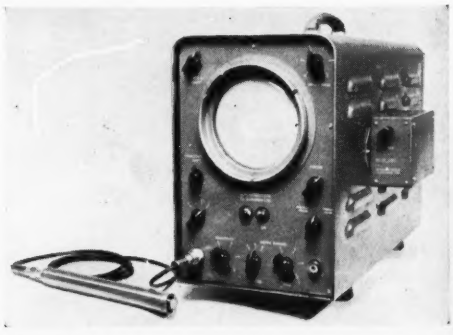




(Above) H.V. power supply unit (3000). **Panax Equipment Ltd.**

(Below) Alpha probe (1355B) with drawer assembly (1355B). **Fleming Radio (Developments) Ltd.**





(Above) Ultrasonic test equipment. **Ultrasonoscope Co. (London) Ltd.**

other general-purpose units. M.39, Mark 1, for example, is an A.C. motor. It comprises a three-phase stator and wound rotor carrying centrifugally-operated speed-governing contacts. A unique feature is the magnetic manual control, enabling speed adjustments to be made without stopping the motor.

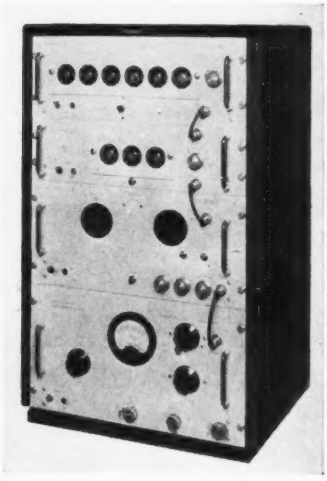
LABGEAR (CAMBRIDGE) LTD.,
Nucleonics Division, Willow Place, Cambridge.

Printing counter (*D*.4123). Comprises two units, a specialized form of dekatron counter and a print-out equipment. The counter, which employs five dekatron tubes, can be used as a scaling unit or counter in time-controlled applications; alternatively, it can be used as a timer in count-controlled timing of existing counting equipment.

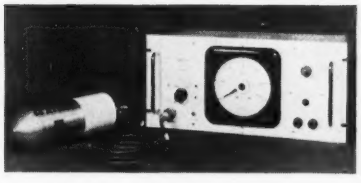
Recording ratemeter (*D*.4124). Highly-accurate integrating ratemeter which gives both a meter indication and a paper record. Four ranges of count rate, up to a maximum of 600,000 per minute.

Nuclear counter (*D*.4122). An automatic scaler incorporating a decade scaler, ratemeter, timer, pre-amplifier, discriminator and stabilized power supplies in a single unit.

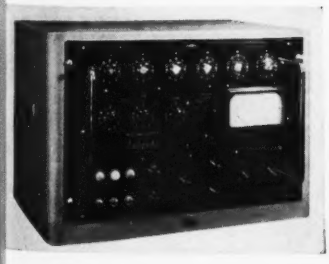
High-level gamma monitor. Indicates the radiation intensity present in close proximity to a high-level source of gamma rays.



(Left) High-speed register (R203)—a three-decade dekatron unit. **Panax Equipment Ltd.**



(Right) gamma monitor. **Labgear (Cambridge) Ltd.**



(Left) Nuclear counter (D4122). **Labgear (Cambridge) Ltd.**

METROPOLITAN-VICKERS ELECTRICAL CO. LTD.,
Trafford Park, Manchester, 17.

Electronic analogue simulator. For use in the study of servo-mechanisms and in the general solution of differential equations.

MULLARD LTD.,
Mullard House, Torrington Place, London, W.C.1.

Electron linear accelerator, 4 MeV. A travelling-wave unit employing r.f. power feedback by means of a rat-race waveguide bridge. Peak pulse power output: 2 MW. Mean power rating: 2 kW.

MUREX LTD.,
Rainham, Essex.

Niobium. This latest addition to the range of refractory metals has properties similar to tantalum, but is only half the density. Available in rod, sheet, wire, seamless tube and as fabricated parts.

Beryllium. Produced in small quantities on behalf of the U.K.A.E.A. Corrosion resistant; low nuclear absorption.

Molybdenum. Tungsten. Tantalum. Zirconium. Fabricated parts, seam- and fusion-welded. Seamless drawn tube in molybdenum, tantalum and zirconium.

NAGARD LTD.,
Avenue Road, Belmont, Surrey.

Wide-range delayed-square-pulse generator (5001). Generates fast-rising pulses and waves; provides a wide range of amplitude, repetition rate, width and delay with direct-reading calibrations together with full flexibility as to polarities of main pulse, pre-pulse and trigger pulse and the ability to trigger from any form of external signal.

PHILIPS ELECTRICAL LTD.,
Century House, Shaftesbury Avenue, London, W.C.2.

Fast scaler (1070*B*). An amplitude discriminator followed by a fast scale-of-ten circuit for applications which involve counting pulses at rates of up to 2×10^8 per second.

SIEMENS-EDISWAN RESEARCH LABORATORIES,
Woolwich, London, S.E.18.

Cold-cathode diodes for counting and storage. Circuits embodying cold-cathode gas-filled diodes can be incorporated as storage stages for the key-sender which replaces the operator's dial on a telephone switchboard.

Transistor circuits with multi-cathode counters. Circuits using multi-cathode counter valves (dekatrons) and transistors form the basis of a telephone-exchange register. For low counting rates, transistor circuits appear more reliable for driving dekatrons than either thermionic valve circuits or cold cathode valve circuits.

Personal gamma radiation monitor. Gives an audible warning when it has received an integrated dose of 0.1 r.

SOLUS-SCHALL LTD.,
15-18 Clipstone Street, London, W.1.

Ultrasonic flaw detector. For the non-destructive examination of machined parts, forgings, welded joints and the determination of wall thickness and so on. Frequency-pulse echo vibration technique registering on an oscillograph screen which can be photographically recorded.

ULTRASONOSCOPE CO. (LONDON) LTD.,
47c Sudbourne Road, London, S.W.2.

Ultrasonic flaw detector. (1*A*). Latest version of this ultrasonic flaw detector features improved minimum range and greater sensitivity.

20TH CENTURY ELECTRONICS LTD.,
Centronics Works, King Henry's Drive, New Addington, Croydon, Surrey.

Very low background end-window counters. End-window counters of small dimensions for the accurate measurement of low activity samples. Other counters include a miniature unit for up to 200 r/hr and a beta-sensitive unit for up to 10 r/hr.

In-pile Experiments with Organic Moderators

UNDER a contract between the Monsanto Chemical Co. and the Naval Reactor Branch, BuShips, Department of the Navy, a preliminary engineering study to determine the feasibility of using organic chemicals as nuclear reactor coolant-moderators has been made. The organics studied were: biphenyl; the tertiary eutectic mixture of biphenyl o-terphenyl and m-terphenyl; HB-40, a partially hydrogenated mixture of the terphenyl isomers; and monoisopropylbiphenyl. A test loop was designed and operated in conjunction with the reactor at the Brookhaven National Laboratory to determine for these organics the specific radiolytic decomposition rate, gas generation rate, induced radioactivity levels, and the effect of decomposition products on the operating characteristics of the system and on the engineering properties of each material.

The study demonstrated that organics are feasible as reactor coolant-moderators, and that the professed advantages are real. The low induced radioactivity found showed, first, that technical-grade organics can probably be used, and, second, that corrosion and erosion was negligible. Corrosion and/or erosion products would have become radioactive during passage through the in-pile section of the loop, and thus would have been detectable in extremely low concentrations.

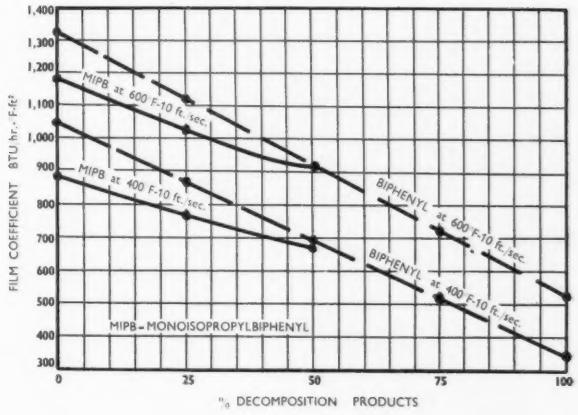
Decomposition rates, although substantial, are not unreasonable. Applying the specific decomposition rate of 30 found for biphenyl, the amount of this organic decomposed in a 100,000-kW nuclear power plant would be about 100 lb/hr. At $0.16 per pound for biphenyl, the make-up cost for the organic would be low. The decomposition products (tars) are completely soluble in the mother fluids in all cases and do not cause fouling. These products do have a decided effect on heat transfer, and it is doubtful if concentrations over 5-10% could be tolerated. This was within the concentration range obtained in the loop studies; thus, measured heat-transfer data can be used without extrapolation. Simple distillation can be used to maintain the desired fluid purity, because the

TABLE 1

	Biphenyl	Eutectic*	HB-40†	MIPB‡
Accumulative nvt (Integrated fast neutron dosage)	1.393×10^{18}	1.66×10^{18}	3.94×10^{17}	1.36×10^{18}
Final decomposition product concentration	7.4%	7.0%	—	10%
Analytical methods	F.P. lowering and distillation	Distillation and IR	—	Distillation
Decomposition product characteristics	Black, glassy solid	Black, glassy solid	—	Black, highly viscous liquid
Fouling characteristics	No fouling detectable	No fouling detectable	No fouling detectable	No fouling detectable
Estimated cost ($/lb)	0.16	1.00	0.17	0.20-0.25
Specific decomposition rate (% decomposed / 10^{18} nvt	29	17	120 (est.)	40-20
Gas generation rate c.c./g decomposed	12	—	56	15
Radiolytic gas composition	H_2 (37%) Sat. (59%) Unsat. (4%)	—	H_2 (95%) Sat. (4%) Unsat. (1%)	H_2 (85%) Propane (14%) Unsat. (1%)
Film coefficients measured at 440° F and 10ft./sec. (BTU/hr., °F. ft.^{2})	1,130	820	600	870
Original flash point (°C)	113	140	177	139
Final flash point (°C)	115	136	136	141
Original fire point (°C)	123	148	194	150
Final fire point (°C)	125	146	184	155
Induced radioactivity (μc/g) (loop samples) ...	0.45	0.38	4.0-0.15	0.111
Induced radioactivity (μc/g) (filtered loop samples)	0.23	0.21	0.15	0.109
Induced radioactivity (unfiltered samples) ...	Fe 59 (6.6%) Na 24 (20.6%) Mr 56 (72.8%)	Fe 59 (13.3%) Na 24 (10.0%) Mn 56 (60.2%) Cl 38 (16.5%)	— — —	Fe 59 (5.4%) Na 24 (8.1%) Mn56 (37.8%) Cl 38 (48.7%)
Upper temperature limit for thermal stability (in N_2) ...	425°C or higher	425°C or higher	Less than 400°C	400°C or higher
Upper temperature limit for thermal stability (in air)	400°C or higher	400°C or higher	—	Between 375 and 400°C

* 36% *biphenyl*, 45% *o-terphenyl*, 19% *m-terphenyl*.
† *A partially* (40%) *hydrogenated mixture of the terphenyl isomers.*
‡ *Monoisopropylbiphenyl.*

(Right) Comparison of heat-transfer characteristics with varying concentrations of decomposition products.



(Below) Diagram of experimental loop used for the in-pile organic experiments.

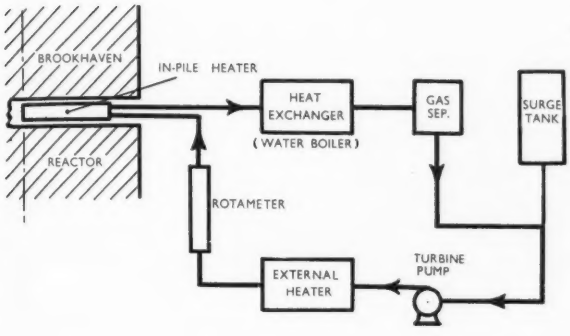


Table 1, opposite, gives the results of irradiation on the various substances used in the tests. Table 2, below, gives their general physical properties.

TABLE 2

Property	Units	Biphenyl	Eutectic*	HB-40†	MIPB‡
Melting or pour point	°C	70	20	−25	−47
Boiling point ...	°C	255	—	362	290
Vapour pressure at:					
100°C	mm Hg	4	—	—	—
150°C	„	43	—	2	10
200°C	„	185	—	15	63
250°C	„	670	—	69	290
300°C	at.	2.4	—	0.33	1.25
350°C	at.	5.55	—	0.82	3.5
Density at 100°C ...	g/c.c.	0.980	1.000	0.930	0.925
„ „ 200°C ...	„	0.880	0.918	0.858	0.857
„ „ 300°C ...	„	0.790	0.837	0.786	0.776
Viscosity at 100°C	centistokes	0.980	2.3	3.800	1.400
„ „ 200°C	„	0.430	0.65	1.200	0.560
„ „ 300°C	„	0.240	0.36	0.520	0.310
Specific heat at:					
100°C	cal./g-°C	0.428	0.413	—	0.470
200°C	„	0.508	0.495	—	0.555
300°C	„	0.590	0.575	—	0.637
Thermal conductivity (100-220°C)	cal./°C-cm-sec.	31.5×10^{-5}	—	—	28.8×10^{-5}
% Hydrogen ...		6.53	—	—	8.28

* 36% *biphenyl*, 45% *o-terphenyl*, 19% *m-terphenyl*.
† *A partially* (40%) *hydrogenated mixture of the terphenyl isomers*.
‡ *Monoisopropylbiphenyl*.

radiation damage products boil at much higher temperatures than the virgin materials.

On the basis of an overall comparison of properties, MIPB appears to be the most practical organic of those tested for use as a coolant-moderator, at least up to 600°F. The combined thermal and radiation damage rate was not determined quantitatively above this temperature for any of the materials tested, although all except HB-40 were proved to be thermally stable up to at least 750°F in an inert atmosphere.

As a result of this study, it was recommended that MIPB be used in a demonstration reactor test where final feasibility can be determined. Such a test is necessary because it is difficult, if not impossible, to simulate completely reactor conditions in a loop system. Sufficient engineering data were obtained in these loop studies to make possible the design of this reactor. However, application of the data acquired in this study to a reactor system was beyond the province of the study and none was attempted.

The use of organics in nuclear power plants offers a real possibility for reducing nuclear power costs. These cost reductions can be accomplished by the simplification of reactor design and the use of less expensive construction materials than are now necessary. The conditions under which the studies were made, although less rigorous by an order of magnitude than those existing or contemplated for nuclear propulsion plants where compact cores and high heat fluxes are necessary, are typical of the conditions that would probably prevail in a central station-type plant. The information resulting from this study should be valuable in economic evaluations of this type of plant and in the conceptual design of such plants.

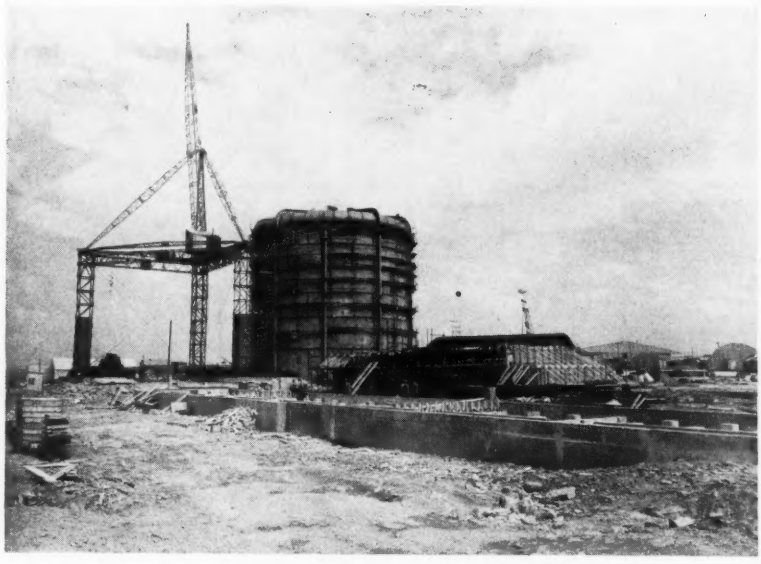
Progress at Dounreay

Substantial Addition to U.K.A.E.A. Research Facilities

WORK on the Dounreay research and development station is entering a new phase. For the past year activity has been largely confined to the constructional work on the two reactors—the fast breeder reactor and the materials-testing reactor—and on the fuel element manufacturing and processing lines which will serve the two reactors. At the same time, a considerable programme of building has been under way to provide laboratories and offices for the staff who will finally work there.

Fast Reactor

The steel sphere has been complete for some time, apart from the top cap, which will not be finally welded into position until the reactor vessel has been finally lowered into position. This has been completed at the works of John Thompson Ltd. in Wolverhampton and transported by sea to Wick, where arrangements were made to strengthen the dock to take the unusually heavy load. Assembly of the metal-to-metal heat exchangers is entering the last stage and some two months ago "clean conditions" were imposed to prevent possible contamination in the circuits. The extra-core area at present is congested, as it was necessary to place all parts in position before final assembly. The assembly operation has, however, been worked out in great detail and is proceeding steadily. The present schedule calls for the installation of the core tank this month, followed by pressure testing of the sphere in May. The reactor should be ready for criticality trials early in 1958.

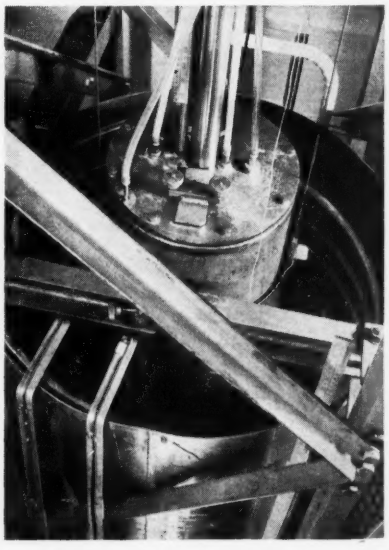


DMTR, which, except for test facilities, is similar to DIDO, nearing completion.

Materials-testing Reactor

The materials-testing reactor—DMTR—is built very much on the same lines as DIDO, described in *Nuclear Engineering* for January. The main biological shield is in position and the lead around the steel tank was poured in January. It is

(Left) A portion of the 24 primary heat exchanger banks nearing completion.



(Right) A view of ZETR, originally installed at Harwell and now transferred to Dounreay.

expected that criticality trials will begin in early autumn of this year.

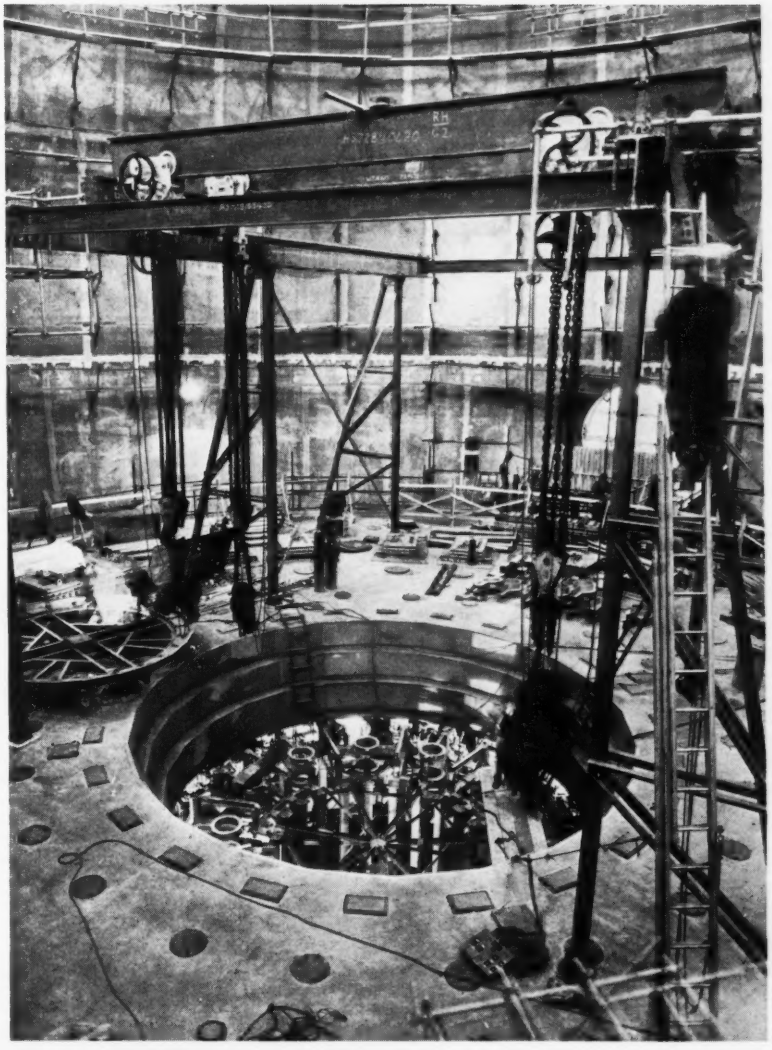
Fuel Treatment Fabrication

The long glove-box assembly line for fabrication of the DMTR fuel elements is now in operation and, after preliminary trials with natural uranium, has begun routine manufacture using enriched uranium. The processing plant for these fuel elements is scheduled to begin operation towards the end of the year.

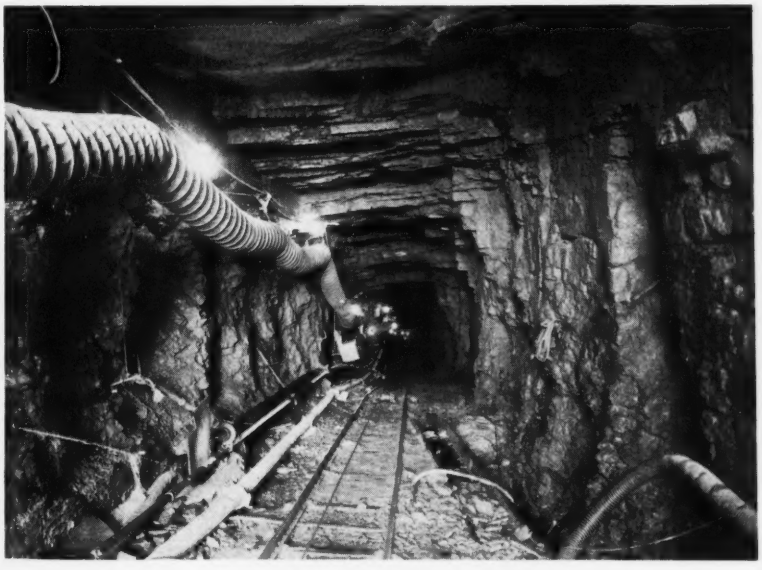
The fuel element fabrication line for the fast reactor which is another large-scale glove-box process line assembly is expected to begin operational trials shortly. The processing plant for these elements is scheduled to begin working towards the end of the year.

R. and D. Projects

Operation of both the fast reactor and the DMTR will be integrated into a comprehensive research and development programme, as these two reactors are designed to provide criticality and radiation facilities for much of the metallurgical side of the R. and D. Group. More staff is being recruited and the Dounreay establishment will provide a substantial addition to the U.K.A.E.A.'s research and development facilities. Part of the programme concerns a group which has been formed for the elucidation of criticality problems. To cut down time at the beginning of the



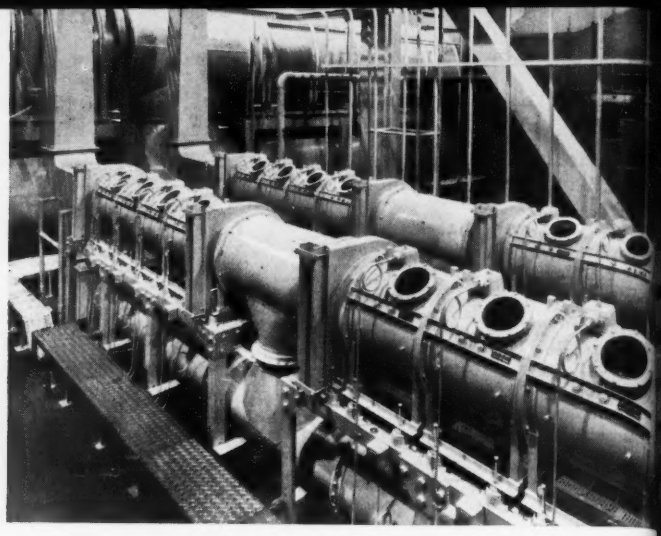
(Right) General view of the top of the fast reactor almost ready for installation of the core vessel.



(Left) A view during the construction of the two-mile tunnel which carries the effluent pipes out to sea.

experiments, the essential parts of ZETR (*Nuclear Engineering*, **1**, 7) are being employed and these have been erected in buildings removed from the main site, controls being operated from a central laboratory 300 ft. away. Immediate investigations that this group is undertaking concern the critical concentrations of the various fissile materials when moderated by various materials in vessels of differing shapes. It is hoped to produce from this series of experiments empirical results which will allow these problems to be amenable to a theoretical treatment.

An Unusual Fan Installation



Several unusual features distinguish a fan installation recently supplied by the Airscrew Co. and Jicwood Ltd., of Weybridge, Surrey, to an A.W.R.E. specification. Intended for ventilation and filtration purposes, the plant had, first and foremost, to satisfy the requirements of the Ministry of Works engineers for a wide variation in system resistance. It also had to satisfy very stringent specifications as to reliability.

Variable-pressure operation is taken care of by the use of axial-flow fans in series, operating as contra-rotating pairs, thus eliminating the necessity for guide vanes, and allowing a certain number of units to operate "windmilling" when maximum pressure is not required.

The fans are of three sizes, 60 in., 48 in. and 18 in., driven by motors of 40, 12 and 1½ h.p. respectively, the normal speeds being 960 r.p.m. for the 60-in. and 48-in. sizes, and 2,850 r.p.m. for the 18-in. The 60-in. fans are arranged in two banks of four units, with a T-piece connection and isolating plate dampers between the two banks. The 18-in. fans are similarly arranged, except that each bank consists of two sets of four fans in series. The 48-in. fans are arranged as two units in parallel, as working fan and standby.

Specified performances for the 60-in. fans were 42,630 cu. ft./min. against 4.31 in. w.g. (two fans working and six idling) or 9.81 in. w.g. with four fans working and four idling. Corresponding performances for the 18-in. fans were 1,200 cu. ft./min. against 4.1 in. w.g. and 11.4 in. w.g. for similar conditions. It is stated that these performances were slightly exceeded on test.

Reliability of the ventilating system as a whole has been achieved by the duplication of the units and the shut-off dampers, so that maintenance can be carried out without affecting normal operation. In addition, special precautions were observed during manufacture. All fans were specially treated against corrosion, the steel surfaces being shot-blasted and zinc sprayed before painting and the aluminium alloy impellers being Pyluminized. The inside surfaces were painted with I.C.I. Kemobel chlorinated rubber paint to complete the protection; the outside surfaces being given a priming coat of zinc chromate, finishing coats of paint being applied after assembly at the site.

Particular attention was given during manufacture to the pressure-tightness of the welded casings and of the assembled joints to avoid all possibility of air escaping. The completed fans were individually tested for leaks with a pressure of ½ lb./sq. in. inside the casings. To give pressure-tightness at the flange joints at the end of the casings, 1-in. thick butyl rubber gaskets are used. A 6-in. diameter flat-glass observation window is provided in each fan casing.

The installation work was carried out by R. B. Stirling and Co. Ltd.

Articulated Handling Equipment

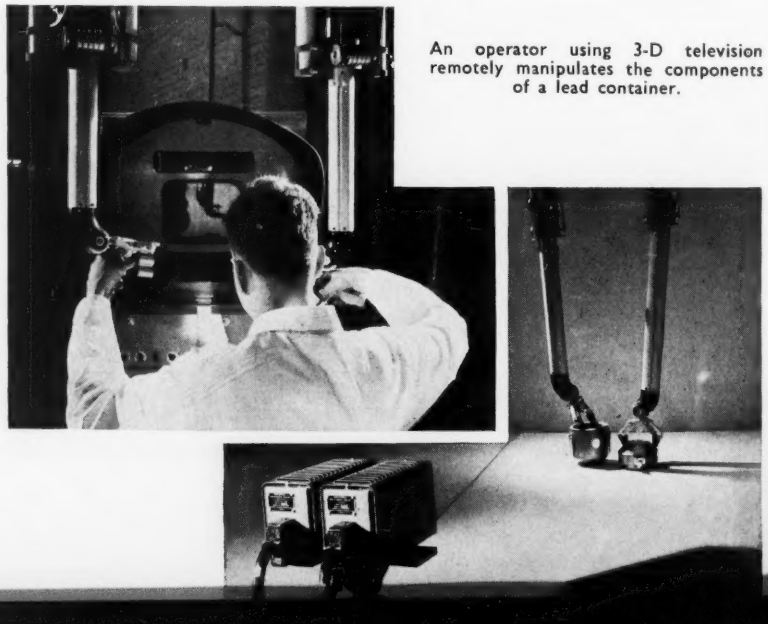
Remote Viewing Assisted by Stereoscopic Television

Rapid developments in handling equipment have taken place over the past few years and *Nuclear Engineering* will be running a series of articles on the whole subject to show the techniques that have now been standardized and the equipment which is at present available.

One form of articulated handling was, however, the subject of a combined demonstration recently by Savage and Parsons and Marconi's Wireless Telegraph Co. Ltd. The Press demonstration coincided with the showing of similar equipment to H.M. the Queen on her visit to Harwell. The illustrated equipment, manufactured by Savage and Parsons Ltd. in conjunction with the A.E.R.E., is entirely mechanical in operation, and is suitable for horizontal distances of some 10 ft. or so. The counterbalancing has been very accurately carried out, and both friction and backlash have been reduced to a practicable minimum. It is therefore possible to utilize the equipment with a high degree of accuracy, and a practised operator can easily withdraw a single match from a box and strike it, as well as performing a number of other feats which, while they would be classified as "circus" tricks, nevertheless give an idea of the capabilities of the equipment.

Remote Vision

In normal use, operation is by direct observation through a high-lead glass window of suitable thickness for the work in hand. Further developments, however, envisage servo-assisted movements over greater distances, precluding the possibility of direct observation, and the stereoscopic or 3-D television has been developed for this purpose. The



An operator using 3-D television remotely manipulates the components of a lead container.

DO YOU SEE

NUCLEAR ENGINEERING

EVERY MONTH ?

The specialized appeal of this journal makes it difficult for your newsagent to carry sufficient extra copies to meet possible casual requests. If you have found this copy of interest why not place a regular order? You will then be assured of seeing *Nuclear Engineering* every month as published and can be certain that no item of technical or industrial importance will pass you by. Simply fill in this card and hand to your usual newsagent or, if more convenient, post to the Publishers.

TEMPLE PRESS LIMITED
Bowling Green Lane,
London, E.C.1, England

Please arrange for me to receive *Nuclear Engineering* every month for 12 months/until countermanded

NAME
_____

NATURE OF BUSINESS
_____

POSITION
_____

ADDRESS
_____

_____

Remittance enclosed/Please invoice me later

Monthly 3/6

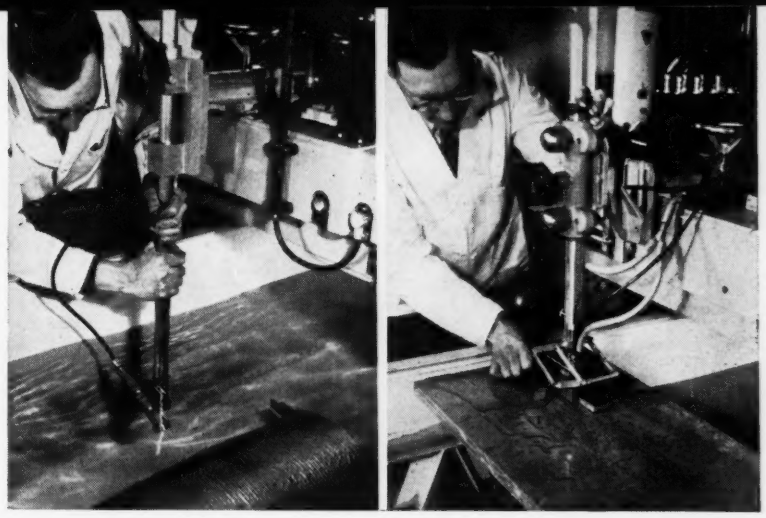
The annual subscription rate is 42/-.
(U.S.A. and Canada $7.00)

See important Note on reverse

2d. Stamp U.K. only.

G.P.O. BOX 147,
TEMPLE PRESS LIMITED,
BOWLING GREEN LANE,
LONDON, E.C.1. ENGLAND

system depends, in essence, on a dual closed-circuit television system utilizing two miniature cameras (of a type described in *Nuclear Engineering*, **1**, 168) mounted side by side. The stereoscopic image is formed by a special monitor system which superimposes the two images by means of a semi-silvered mirror. Correct separation of the left and right eye images is achieved by the use of polaroid filters of different senses on the two screens, the operator wearing spectacles with similar screens polarized in the appropriate direction.



(Above, left) Setting up the Kelvin Hughes probe unit for the inspection of light-alloy billets using the immersion technique. (Above, right) Setting up for gap testing of steel plate.

Automatic Flaw Detection

THE application of ultrasonics for non-destructive testing is now so well established that it is not surprising to learn of a fully-automatic system. Nor, for that matter, is it surprising that the company responsible for this new technique is Kelvin and Hughes (Industrial) Ltd., of 2 Caxton Street, London, S.W.1.

Kelvin and Hughes are, of course, pioneers in the development of ultrasonics. Their echo sounders for indicating the depth of sea are now used throughout the world; the first Hughes ultrasonic equipment for testing solids was introduced in 1943. With this method of testing, a beam of high-frequency sound is injected into the specimen. Porosity causes a premature reflection of the pulse which can be shown on a cathode-ray tube.

The new automatic system is known as Autosonics—a combination of the words "automatic" and "ultrasonic". To cater for the wide range of applications, the system has been made as flexible as possible. Mechanically, a predetermined scan or search plan is accurately followed by a probe system, thus ensuring that all information relevant to position and size of the defect in the specimen is indicated and recorded.

Selection of the type of scan is governed by the nature and position of the probable defects, the dimensions and shape of the specimen and production conditions. It is thought that the four main methods of test will be (a) to bring easily movable test pieces to the instrument; (b) to incorporate the equipment in a production line; (c) to automatically feed small components to the probe surface; or (d) to mount the equipment on a carriage so that it can be propelled over the surface to be tested.

The electronic circuits comprise the following sections: flaw detector; automatic gain control; automatic flaw alarm and recorder; and system fault alarm.

The flaw-detection section generates ultrasonic sound which is transmitted into the material, as a sequence of energy pulses, by an inspection probe coupled to the surface of the material by a liquid. It also amplifies the reflected pulses, and presents the complete sequence of events as a trace on a cathode-ray tube. The automatic gain control section maintains the sensitivity of inspection constant by monitoring the amplitude of a selected echo pulse, and, wherever necessary, alters the gain of the amplifier to compensate for any change in it.

The automatic flaw alarm and recorder section operates warning lights, bells or klaxons when a flaw indication is obtained on the cathode-ray-tube screen. The sensitivity can be adjusted so that it will respond to small or large indications, ignoring those which are less than the present level. The output from this section can be used to operate various recording systems—for example, to provide a plan position indication of any defect present in a plate. Finally, there is the system fault alarm section. In the event of the selected monitor signal falling below its control level for any reason, an alarm will operate which will stop the scanning machinery.

SALIENT DATA

Frequency range: 0.5 to 10 Mc/s. Frequencies up to 25 Mc/s available to special order.

Inspection range: Up to 25 ft. (8 metres).

Probes: Common, combined or separate transmitter and receiver systems.

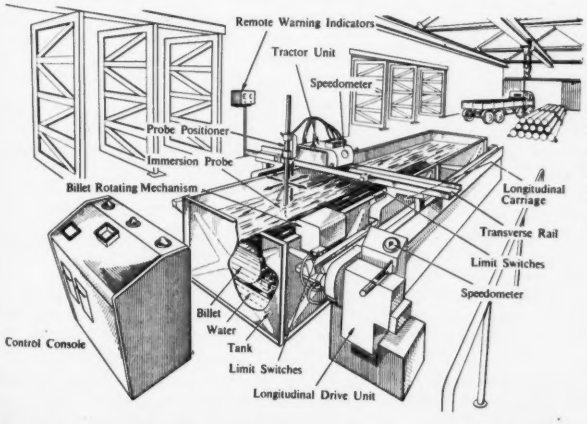
Widths: ½ in. to 6 in. (5 mm. to 150 mm.).

Pulse lengths: Down to 3 cycles at half power level.

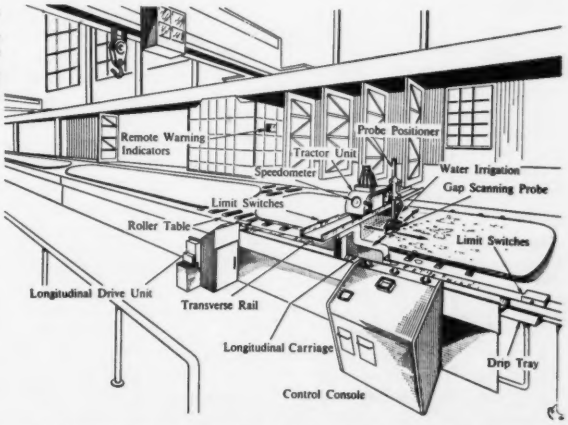
Dead zones: 1/10 in. (2.5 mm.) at 2.5 Mc/s test frequency for targets equivalent to a 3/64-in. diameter (1.25 mm.) flat bottom hole in aircraft-type materials. 1/100 in. (0.25 mm.) at 2.5 Mc/s for gross laminar-type defects.

Automatic monitoring and flaw alarms: Adjustable from 1/10 in (2.5 mm.) below top surface to 25 ft. (8 metres), both in location and width.

Inspection speeds: For targets equivalent to 3/64 in. (1.25 mm.) flat bottom hole, up to 100 ft. per minute (30 metres per minute). For gross defects, up to 400 ft. per minute (120 metres per minute).



Autosonics equipment for the automatic inspection of light-alloy billets by the total immersion technique.



The automatic detection of lamination in steel plate can be effected by means of the gap-testing method.

Technical Papers and Publications

INSTITUTE OF METALS

The Status of the Beryllium Industry in the United States of America *by Bengt Kjellgren (Brush Beryllium Corporation of America). London local section, Institute of Metals, March 7, 1957.*

There are two companies in America concerned with beryllium production, the Beryllium Corporation, which is fully integrated for the production of beryllium copper alloys from the ore, and the Brush Beryllium Corporation, which produces beryllium copper and pure beryllium by powder metallurgy processes. Both companies' plants are being extended for the production of one million pounds of vacuum-cast beryllium ingots for the United States Atomic Energy Commission.

Electrolytic methods are not used for the production of beryllium in the U.S.A. The method used is a thermal reaction between beryllium fluoride and magnesium metal. The pellets so formed are cut into chips and ground in dry nitrogen and stored in airtight containers. To produce massive metal, the powder is compressed in heated moulds of steel or graphite and a density of 1.84 to 1.85 achieved. The compacts contain from ½ to 1% of oxide, which appears to be beneficial to the properties of the metal.

To all intents and purposes, beryllium is as light as magnesium, is non-magnetic and dimensionally stable. It has a strength/weight ratio higher than aluminium, titanium and, in some cases, stainless steel. Its cofficient of expansion is the same as stainless steel and it has a comparatively high heat conductivity, this being between that of aluminium and magnesium. The heat capacity of beryllium is twice that of aluminium and its heat fusion is three times that of aluminium, its melting point is 1,278°C and it resists oxidation up to 800°C.

In spite of its high cost, beryllium may find useful application in instrument manufacture, due to its high strength ratio, coupled with rigidity and high corrosion resistance. In the atomic energy field its superior properties at elevated temperatures make it competitive with zirconium, particularly for high-temperature reactors. It is of interest to note that, for atomic energy use, beryllium oxide has properties as good in many respects as beryllium metal.

ROYAL INSTITUTION

Lecture delivered at the Royal Institution on Friday, March 8.

European Organization for Nuclear Research *by Sir Ben Lockspeiser, K.S.B., D.Sc., F.R.S.*

The resources, human and material, required for scientific research have grown in some fields to large dimensions in recent years. This is particularly so in the field of nuclear physics, where the means necessary for controlled experimentation have increased beyond the single capacities of most nations. The European Organization for Nuclear Research (CERN) was, therefore, brought into being to enable twelve European countries to achieve together what they are not able to do alone.

The first task of the Organization was to provide itself with research tools, chief of which is the particle accelerator. Two machines,, each of a different type, are being built at Meyrin, near Geneva: one, a synchro-cyclotron, in which the path of the accelerated particle is a flat spiral, and the other, a proton-synchrotron, which accelerates the particle in a repeated circular path. Their energy levels are 600 MeV and 25 GeV respectively.

The present staff, drawn from various countries, numbers about three hundred. A multi-national venture of this kind requires its own form of organization to govern itself and to maintain essential relationships with the Governments of member States. It requires also an administration capable of dealing with both the present constructional period and the succeeding period, now beginning, when scientists from various countries will be enabled to use the machines for limited periods, dependent on their programme of work.

INST. CHEM. E.

Chemical Processing of Nuclear Fuels *by C. M. Nicholls, B.Sc. (Eng.), A.R.I.C. (member), and R. Spence, C.B., Ph.D., D.Sc., F.R.I.C. (chemical engineering division, A.E.R.E., Harwell, and chief chemist and head of chemistry division, A.E.R.E.) The Institution of Chemical Engineers, February, 21, 1957.*

Processing of nuclear fuels is an essential aspect of a nuclear power programme and the economics of such separation can have a considerable bearing on the ultimate cost per kW. Apart from the recovery of plutonium and uranium, fission products must be extracted in the form which allows easy storage with concentration preferably by direct evaporation or the separation of the most useful long-lived radio-isotopes. The irradiation time for a fuel element has a considerable bearing also on the problem, as, for example, very long irradiated natural uranium fuel elements will contain a significant fraction of U 237 which is radioactive and may lead to complex shielding problems in the later stages of the process.

In general, the aim is to achieve a high degree of separation of the fission products at the first stage to allow subsequent stages to be only lightly shielded. In these subsequent stages, however, criticality is a major issue.

Extraction processes can be classified under the headings of liquid-liquid extraction, vapour liquid processes and pyroporic processes.

In all these the basic operations concern decanning of the fuel elements, followed by extraction of the components and purification, with final reprocessing of the useful components and storage of the highly active wastes and dispersal of the only lightly active wastes. Possible application of the various types of process are considered in relation to the technical and economic factors. It is concluded that there is need for versatility in processing plants for some time to come, as neither reactor nor fuel elements have become standardized. Solvent-extraction processes provide the best compromise at the present stage.

INST. MECH. E.

Rotary Shaft Seals—The Sealing Mechanism of Synthetic Rubber Seals Running at Atmospheric Pressure *by E. T. Jagger, B.Sc. (Eng.), Ph.D. (Associate Member) (chief engineer, George Angus and Co. Ltd.). Institution of Mechanical Engineers, March 29, 1957.*

The paper describes an investigation into the mechanism of sealing by conventional rubber seals on rotating shafts. These consist essentially of an annular U-section of synthetic rubber, the lower and outer faces being reinforced by a metal L-section, and the sealing thrust maintained by an annular spring. In order to simplifiy the investigation, the conventional seal was modified and the loading was changed from a radial direction to an axial one. Tests were then made of the contact load against the torque, from which could be derived the coefficient of friction and a note made of the point of transition between sealing and leaking. The smooth shape of torque load curves when passing through the sealing point indicated that there was no essential bearing difference between the sealing and leak conditions, indicating that an oil film exists even when well past the sealing point. The logical deduction therefore is that the seal is perfected by the formation of a meniscus and this was proved by arranging the meniscus to be broken by introducing an oil film on the normally dry part of the shaft. In these circumstances, leakage occurred almost irrespective of the magnitude of the load applied, although the volume of leakage was dependent upon the load.

Personal

Mr. W. R. Owen.

Mr. L. G. Piggott.

Mr. Dudley Saward.

Mr. V. Thomas.

Mr. A. V. Clifford, who has been a member of the editorial staff of *Nuclear Engineering* for the past year, has been appointed editor of our associated journal, *The Overseas Engineer.*

Mr. W. Bryson will retire from his position as general manager of The Motherwell Bridge and Engineering Co. in July of this year. He will be succeeded by **Mr. James McLean,** B.Sc., A.R.T.C., chief designer.

Mr. A. O. Ahlquist, M.A., A.M.I.Mech.E., has been appointed assistant sales manager, mechanical department of Metropolitan-Vickers Electrical Co. Ltd., and **Mr. N. J. Austin,** A.M.I.Mech.E., A.M.I.M.E., assistant in the department.

Mr. K. G. Sinclair has been appointed chairman of Griffin and George Ltd., **Mr. N. McKinnon Wood** has been appointed vice-chairman and relinquishes his appointment as managing director. He is succeeded by **Mr. N. Trepte.**

Mr. F. H. Roberts has been appointed a director and chief engineer of John Thompson (Australia) Pty. Ltd., a member company of the John Thompson Group.

Mr. V. Thomas, general sales manager in charge of all home sales of Fielden Electronics Ltd., is to organize and expand the company's export division, and will be responsible for all export activity.

Mr. G. A. Vowles, O.B.E., M.I.Mech.E., M.I.E.E., has retired from the position of controller of the Central Electricity Authority's Yorkshire division. **Mr. G. R. Peterson,** B.A., M.I.E.E., M.I.Mech.E., generation operation engineer of the company, has been appointed deputy chief engineer (generation and system operation).

The Rt. Hon. A. R. W. Low, P.C., C.B.E., D.S.O., T.D., M.P., has been appointed a director of the General Electric Co. Ltd.

Mr. W. R. Owen, manager of the Sheffield branch office of Honeywell-Brown Ltd., has been promoted to manager for the north-east region of the company. **Mr. A. Hague,** Mr. Owen's deputy, succeeds him as manager of the Sheffield office.

Mr. L. G. Piggott, formerly with the service division of Alfred Imhof Ltd., has been appointed sales manager.

Professor Niels Bohr, president of the Danish Atomic Energy Commission and director of the Institute for Theoretical Physics in Copenhagen, has been awarded the first $75,000 Atoms-for-Peace prize.

Mr. Thomas Reis, has been appointed executive vice-president and general manager of the Satnuc Co., formed by six French companies in order to study industrial applications of nuclear energy.

Lord Bridges is the chairman of the governing board of the National Institute for Research in Nuclear Science, which aims to provide, for use by universities and others, facilities and equipment beyond the scope of individual universities and institutions carrying out research in the nuclear field. Members of the board are: (universities) **Sir Phillip Morris, Sir James Mountford, Professor, N. F. Mott, Professor H. S. W. Massey, Professor J. Diamond, Professor R. Teieros, Dr. D. H. Wilkinson;** (University Grants Committee) **Sir George Thomson, Mr. J. C. Gridley;** (Royal Society) **Sir David Brunt;** (Atomic Energy Authority) **Sir John Cockcroft, Sir Donald Perrott, Dr. B. F. J. Schonland;** (Department of Scientific and Industrial Research) **Dr. H. W. Melville, Professor P. M. F. Blackett.** Grants on the whole will be made through the U.K.A.E.A.

Dr. Eugene Greuling, associate professor of physics at Duke University, has joined the John Jay Hopkins Laboratory for Pure and Applied Science of General Dynamics Corporation's general atomic division for a six-month period. Dr. Greuling will work with Dr. Lothar W. Nordheim on an article on the theory of beta decay.

Mr. L. K. Brindley, deputy chairman of the Mond Nickel Co. Ltd. and of Henry Wiggin and Co. Ltd., and **Mr. A. Parker,** a director of the two companies, have retired.

Mr. R. Turner, chief engineer of Powel Duffryn Technical Services Ltd., has been appointed to the board of the company in place of **Mr. G. W. Alexander,** chief engineer of Powell Duffryn Ltd.

Mr. Dudley Saward, O.B.E., has been appointed managing director of Texas Instruments Ltd., a newly-formed U.K. manufacturing subsidiary of U.S. Texas Instruments Inc.

Dr. D. Taylor, head of the electronics division A.E.R.E., Harwell is to join Plessey Nucleonics Ltd. as director and manager.

Dr. Ing. G. Cavalazzi, formerly with the Societa "La Centrale" in Milan, has been appointed technical manager of the Societa Elettronucleare Italiana in Rome.

MEETINGS TO NOTE

April 2.—Institution of Chemical Engineers (B.N.E.C. meeting at the Royal Institution): "The Homogeneous Aqueous Reactor", R. Hurst, I. Wells and D. Newby.

April 4.—I.E.E.: The Kelvin Lecture, "Infra-red Radiation", G. B. B. M. Sutherland.

April 4.—Institute of Metals (Leeds Metallurgical Society at the University, Leeds): "Fatigue in Metals", P. J. E. Forsyth.

April 4.—Society of Instrument Technology (at Northampton Polytechnic, St. John Street, London, E.C.1): Discussion on "Education", opened by C. J. Charnley and S. W. J. Wallis.

April 5.—Women's Engineering Society (at 45 Gt. Peter Street, London, S.W.1): "Use of Electronic Computers in Engineering", Miss Jill Robinson (Ferranti Ltd.).

April 8-10.—Physical Society: Conference on Physics of the Solid State (at University of Nottingham Physics Department). (Non-members welcome: conference fee 10s.)

April 9-11.—Institution of Chemical Engineers: Symposium on Chemical Engineering Education at the University of Birmingham.

April 9.—Institution of Civil Engineers: "Control of Flow by Gates and Valves", H. D. Morgan.

April 9.—Society of Instrument Technology (Manchester section, at Manchester College of Technology): "The Science and Art of Instrumentation", J. K. Burkitt.

April 10 *and* 11.—I.E.E. (North Scotland Subcentre at Aberdeen on April 10 and Dundee on April 11): "Nuclear Reactors and Power Supply", G. W. K. Ford.

April 11.—Institute of Metals (Liverpool Metallurgical Society, at 9 The Temple, Dale Road): "Vacuum Techniques in Metallurgy", M. Harper.

April 17.—Society of Instrument Technology (Newcastle section, at Kings College, Stephenson Building): "Data Read-out Equipment and Possible Applications to Process Control", A. St. Johnston (Elliott Bros.).

May 1.—Institute of Metals (B.N.E.C. meeting at Church House, Westminster, S.W.1, 10 a.m.): Half-day discussion on "Metallurgy of Niobium".

May 2.—Institute of Metals (Leeds Metallurgical Society, at the University of Leeds): "Some Aspects of Creep", J. D. Meakin

New Books

Atomic Energy for Your Business, *by Arnold Kramish and Eugene M. Zuckert.* (269 *pp.*, 17 *illustrations. David McKay Company Inc.*, $3.95.)

As its secondary title, "Today's Key to Tomorrow's Profits", indicates, this is a book for the business man who has neither the time nor the inclination to delve deeply into theory, but wishes to be able to appreciate what nuclear energy and nuclear techniques can do for him, as well as giving him sufficient background to discuss the social and political implications of nuclear energy; impact on industry, and the current problems, national and international, that require solution. There are extensive technical supplements which, like the remainder of the book, are written in a simple and readable style.

Exploration for Nuclear Raw Materials, *by Robert D. Nininger.* (293 *pp.*, 60 *illustrations. Macmillan and Co. Ltd.*, 55*s. net.*)

One of the Geneva series on the peaceful uses of atomic energy, this book represents some 130 papers presented on the subject, which the author, assistant director, to the U.S.A.E.C., of raw materials for exploration has reduced to readable proportions. Commencing with the geology of uranium and thorium, Part 1 of the book reviews the natural occurence and the origin of these materials. Part 2 is devoted to the techniques of prospecting, including geologic, radiometric, geophysical, geochemical, botanical and hydrogeochemical methods. Exploration drilling and subsurface radiometric techniques are also covered. In addition to a main list of conference papers, comprehensive references are given for each chapter. Subject and name indexes are provided.

Radioactive Materials and Stable Isotopes. *Catalogue No.* 4. *Isotope Division, A.E.R.E., Harwell.*

The fourth edition of the isotope catalogue has now been published and can be obtained from the Isotope Division, A.E.R.E. The general form of the previous editions has been retained, but the individual sections have been expanded. The principal section consists of a table giving the properties and availability of individual pile-produced radio-isotopes with a much greater specification of the branching ratio and radiation energies than has been possible hitherto. The figures have been culled from a great number of sources and, where appropriate, references are appended. Some of these revised figures will assist in explaining apparent inconsistencies in the characteristics of the radiations as against previously acknowledged information. The revised data of thulium-170 are an example.

The section on cyclotron-produced and stable isotopes has also been expanded to include those materials which have become available since edition No. 3. Much useful ancillary information is given on general topics, such as the control of health hazards and the preparation of radio-isotopes. Details are also included of the facilities offered by the Technological Irradiation group for high-intensity ionizing irradiation of materials. Tables are also given of radio-isotopes classified in terms of half life.

The production of this catalogue has always been characterized by a simple and straightforward layout with the minimum of complexity in the presentation of the relevant information. There is a comprehensive index and the catalogue must form a valuable reference book, not only for those who specifically need to purchase radio-isotopes but also those who wish to refer to essential basic information.

Reactor Shielding Design Manual. *Edited by T. Rockwell III.* (*McGraw-Hill Book Co. Inc., N.Y.*, 1956 *XII* + 481 *pp.* 45*s.*)

The possible application of nuclear power to marine propulsion in this country renders especially timely the publication of Rockwell's manual on shield design. The *Nautilus* programme and the development of the pressurized-water reactor at Shippingport, Pa., have had the effect of stimulating experimental work in the U.S.A. on shield materials, and have made available, in addition, methods of calculation for many shield problems. The need for correct shield design in ships (and, *a fortiori*, aircraft) is apparent, but even in large natural-uranium graphite-moderated reactors care in shielding design may lead to substantial savings in shield weight, and hence in civil engineering costs.

The *Reactor Shielding Design Manual* deals specifically with the problems of shielding water-moderated reactors and their coolant loops, but the experimental data in the book, cautiously used, are of wider application, while the empirical theories and formulæ are quite general and with some exceptions quite satisfactory. The ten chapters include sections on shielding theory, the attenuation of nuclear radiations, shield engineering, shut-down radioactivity and the effect of ducts; two final chapters include many standard mathematical results and a valuable tabulation of experimental data. In a commendable effort to make the information widely available as soon as possible, the editor has included some material which future work may modify, while some of the loose writing that characterized the original U.S.A.E.C. reports on which the book is based has found its way into the present volume. It is certain that critical examination of the present data will lead to simplified and more general methods of shielding calculation; such an examination will have the effect of reducing the bulk of any future manual below the five hundred pages here required.

This book is both valuable and difficult to use: it contains the information needed for shield design, and where the information is presented in graphical form the illustrations are accurate and clear. It is poorly indexed and the arrangement of contents is such as to make its frequent use as a reference book tedious. In choosing the chapter order, the editor had in mind the engineer confronted with the design of a complete shield system. In the reviewer's opinion, such a reader is exceptional and most shielding engineers require a reference manual in which any individual calculation or set of data can quickly be located. They may find the arrangement of the *Reactor Shielding Design Manual* perverse, while having cause to be grateful for the information it contains and for its freedom from inaccuracies.

R.H.

The Oil Engine Manual. *Edited by D. S. D. Williams, A.M.I.Mech.E.* (330*pp.*, 133 *illustrations, plus tables and charts. Temple Press Ltd.*, 18*s. net.*)

Although oil engines may seem far removed from nuclear engineering, the Diesel engine is an integral part of practically every nuclear power scheme of any size and, in any case, this book hardly needs an apology for its review. This is the sixth edition of an exceedingly useful handbook that covers the field in three stages. First comes technical background, from the history of development to operating costs and utilization of exhaust heat. Part 2 is devoted to a review of current British designs, with tables of technical details. Part 3 is an appendix of statistics, standards and specifications and includes "Datagraph" charts for easy comparison of engine designs and for easy computation of electricity costs on the basis of two-part tariffs.

Commencing with the May issue, "Nuclear Engineering" will be published on the fourth Saturday of every month. The May issue will be published on April 27.

(Above) During the Royal visit to A.E.R.E., Harwell, H.M. the Queen was escorted by Sir John Cockcroft. (Above right) The Queen sees DIDO with Dr. J. V. Dunworth.

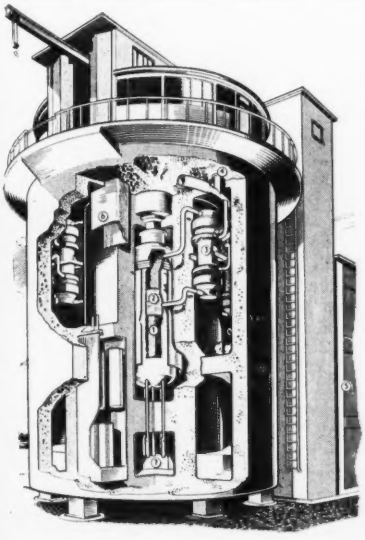
World News

Mr. H. J. Grout, deputy head, reactor division, greets H.M. the Queen outside DIDO.

INTERNATIONAL

The VIII European Prize Cortina Ulisse of value 1 million lire will be awarded to a work of popular science making clear the possible peaceful applications of atomic energy. Original works printed for the first time in Europe during the last five years shall be taken into consideration. The entries must be sent in five copies, either by the author or by the publisher, to the editor of *Rivista Ulisse*, Sezione Premio Europeo Cortina Ulisse, Corso d'Italia 43, by May 31, 1957.

The representatives of EURATOM, Monsieur Louis Armand (France), Herr Franz Etzel (Germany) and Professor Francesco Giordani (Italy), completed a tour of U.K. atomic energy installations and discussions with members of the Authority and members of the Consortia on March 1. These representatives will report back to EURATOM on their findings, but these are of a preliminary nature only. Teams of experts from both the U.K. and the U.S.A. will later visit Europe for more detailed discussions. It was expected that the treaty instituting the European Atomic Energy Community would be signed on March 23.



The Mitchell-A.M.F. reactor power plant. Key: 1: reactor core; 2: boiling water; 3: heat exchanger; 4: steam outlet; 5: turbine house and administration block; 6: fuel storage; 7: control mechanism bay.

GREAT BRITAIN

H.M. The Queen, accompanied by Prince Philip, Duke of Edinburgh, made an extensive tour of A.E.R.E., Harwell, on March 1. During their tour they were given a comprehensive account of the establishment's activities and were able to see many of the groups at work. A number of exhibits had been staged, a special feature being made of the remote-handling equipment.

Mitchell Engineering Ltd. have announced that, with their American associate, A.M.F. Atomics Inc., they have received an order from Rheimisch-Westfalisches Elektrizitatswerk A.G. for a boiling-water nuclear power plant designed to give an electrical output of 15,000 kW. The value of the total order is $5.3 million, of which Mitchells will be responsible for approximately three-fifths. A.M.F. will supply the core and control gear and instruments, whilst German engineers will undertake the bulk of the civil work, excepting the design of the containment vessel, which will be of steel-clad concrete. Turbine equipment will also be supplied by Germany. The site for the reactor is not finally settled, but it will probably be on the Rhine within easy reach of Dusseldorf. Construction is scheduled to start in July; design work is not yet complete. The unit is substantially the same as that described in *Nuclear Engineering*, **1**, 123, except that the steam conditions have been downgraded at the turbine to a pressure of 600 p.s.i. (dry saturated), but has been restyled to be located above ground if required. Provision has also been made for the addition of forced circulation to the natural circulation, if this should be required. It is understood that eight companies tendered for this particular reactor, which is essentially a proving reactor for the boiling-water type.

The nuclear-propelled submarine which is being developed by Vickers Nuclear Engineering Ltd., comprising Vickers-Armstrongs Ltd., Rolls-Royce Ltd. and Foster Wheeler Ltd., in co-operation with the naval section at A.E.R.E., Harwell, is to be built at Vickers' yards in Barrow. The reactor will be of the pressurized-water type.

(Left) To handle extra-heavy plates for reactor pressure vessels, Whessoe Ltd. are installing this 65-ton charging machine built by Gibbons Bros. Ltd.

ZEPHYR has been operating for some months as a fast-slow reactor. The experiments now in hand are analogous to those being undertaken at the Argonne National Laboratories on the Zero Power Reactor No. 5 (ZPR-V) which also comprises a fast core surrounded by a thermal section containing the control system.

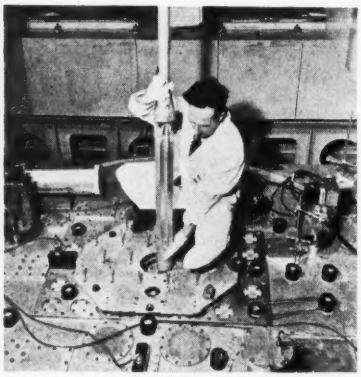
NERO, the zero power experimental reactor, became critical on February 23. This is a versatile unit designed for performing nuclear physics experiments on a graphite - moderated thermal system using heterogeneous fuel elements. The following companies were concerned with the construction work: Saben, Hart and Partners Ltd., London —detail design work; Technical Design and Tool Co. Ltd., Reading—detail design work; March Ltd., Reading—steelwork fabrication; R.O.F., Nottingham—roof trolleys; H. M. Hobson Ltd., Wolverhampton—control mechanisms.

A 10-kilo-curie cobalt-60 irradiating cell at Grove, Wantage, Berks. A dosimeter pattern is being set up for investigation of the biological application of fission products.

The revised nuclear energy programme for Great Britain was announced on March 5. The new programme calls for the installation of 18 stations by the C.E.A. and one by the S.S.E.B., with a total generating capacity between 5,000 and 6,000 MW, over the next nine years (see Editorial). The capital cost of the stations is estimated to be in the region of £1,460 million. In his address to members of the Parliamentary and Scientific Committee, Sir John Cockcroft discussed the improvements in design over Calder Hall and suggested that the second generation of reactors should see a greater output from the same sized reactors, leading to a reduction in capital costs of the order of 20%. The third generation would require more radical changes in design, involving the use of plate-type elements, beryllium sheathed or ceramic. The possibility of using enriched materials should not be ruled out.

The Northern Ireland nuclear power programme recently announced calls for a 150-MW station to be brought into operation in 1963-64. This scheme is substantially the same as that suggested in the White Paper CMD.355 (*Nuclear Engineering*, **1**, 181).

The North of Scotland Hydro-Electric Board's report for 1956 indicates that thermal generation is required to meet the steady annual growth of load and to provide support for hydro-electric generation in times of drought. Consideration is being given to the installation of a nuclear power station and a number of sites are being investigated.



A new photograph of DIMPLE (deuterium-moderated pile, low energy). Its extreme simplicity (canned uranium rods; heavy-water tank; graphite reflector) and low power make it a highly-flexible research tool.

In Brief

Sir Edwin Plowden, chairman, U. K. A. E. A., began a visit to the Union of South Africa on March 15.

The Civil Lord of the Admiralty will head a committee to co-ordinate the application of nuclear propulsion to merchant ships.

Titanium condenser tubes—solid drawn from I.C.I. titanium-130—are undergoing service trials at Uskmouth power station, Newport.

FRANCE

An O.E.E.C. European Productivity Agency-sponsored conference on nuclear energy for management is being held in Paris from April 1 to 6.

The power programme for France embodied in the current five-year plan provides for an expenditure of £250 million on nuclear research and power production. Proposals include the installation of 850 MW nuclear power by 1965.

GERMANY

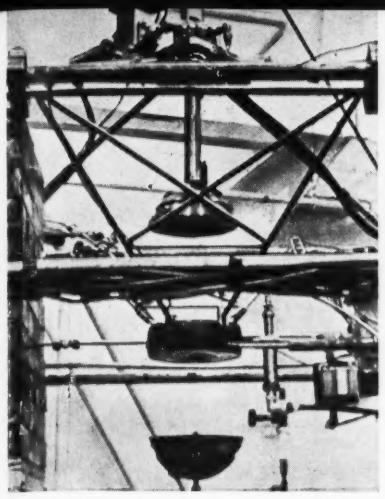
A research reactor for West Berlin, announced in *Nuclear Engineering*, March, 1957, is to be built by Atomics International. This will be a 50-kW solution-type reactor fuelled with uranyl sulphate (*Nuclear Engineering*, **1**, 344). The same company has also received a contract for the construction of another research reactor at the University of Frankfurt. The A.E.C. has announced that it has agreed to the first export to Western Germany of a research reactor. This is a 1-MW swimming-pool type, which is to be constructed by A.M.F. near Munich.

A visit to Britain has recently been undertaken by Sir Siegfried Balke, the Western German Minister of Atomic Affairs, the object being to discuss economics of nuclear power reactors. He anticipated that Western Germany would shortly be embarking on a £58 million investment programme to give an installed capacity of nuclear power by 1965 of 500 MW or more.

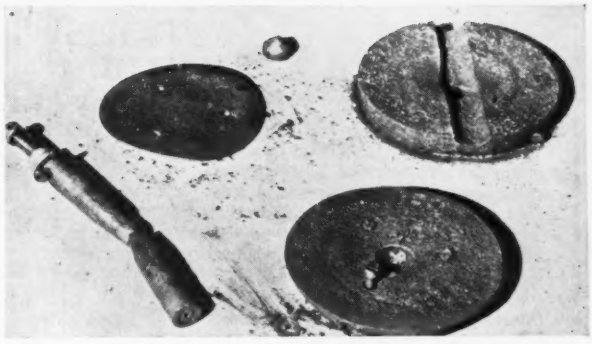
The German Atomic Energy Bill, which has already passed its first reading in the Lower House, contains a clause making it obligatory for companies handling active material to be insured up to £2 milion approximately.

HOLLAND

A new Netherlands-U.S. agreement has been drawn up to cover the exchange of classified information on the peaceful uses of atomic energy over the next ten years. Previous agreements made in 1955 are superseded.



(Left) The three components of the sphere shown here were destroyed when the critical assembly burst under the heat of a runaway chain reaction at Los Alamos on February 12.



(Right) Portions of the Lady Godiva critical assembly knocked apart by thermal shock.

JAPAN

A final delegation is to be sent by the Japanese Atomic Energy Commission to the U.K. to obtain last-minute details on a nuclear power station. General reports indicate that Japan will buy a British nuclear power station with an output between 100 and 280 MW.

An atomic energy bill has been drafted and will shortly be presented to the Diet. It is understood that permission will be required from the J.A.E.C. before any private companies can deal with radioactive materials.

A joint U.S.-Japan exhibition will be held in Tokyo and Osaka during May to display the latest developments in atomic energy.

NORWAY

A Norway-U.S. agreement for co-operation in the field of nuclear energy was signed in Washington on February 25. The bilateral agreement concerns the access to information on reactors and provides for the purchase of up to 500 kilograms of U 235.

National budget for 1957-58, presented at the beginning of March by the Finance Minister, totals approximately £275 million. The Norwegian Institute of Atomic Research receives over £830,000 towards the two reactors Kjeller and Holden.

U.S.A.

The temperature surge on the Los Alamos critical assembly, dubbed Lady Godiva, resulted in a certain amount of damage to the components. The accident which occurred on February 12 has been widely reported, frequently under the misnomer of an explosion. At the time of the accident, the assembly was being used as a source of neutrons for some experiments on the behaviour of a uranium graphite assembly under intense bombardment. The power surge was greater than expected and the resultant thermal shock caused disintegration of some of the components.

The Submarine Intermediate Reactor (SIR) developed at Knolls Atomic Power Laboratory and forming the prototype of the submarine *Seawolf* is to be shut down. The 225-ft. steel sphere which houses the reactor will be retained intact for future use in the experimental operation of prototype nuclear power plants.

Grants totalling nearly $1,200,000 have been awarded by the Atomic Energy Commission to aid nuclear technology training. The grants will be made to 15 American educational institutions for the equipment of laboratories and for training courses.

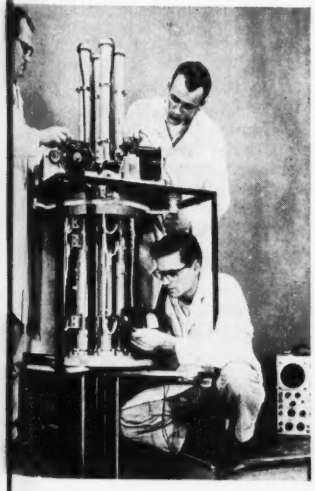
Building of the fast reactor by the Power Reactor Development Co., of Detroit, Michigan, is likely now to go ahead as planned, following the A.E.C.'s refusal to allow an interlocutory appeal following the results of the hearings to the objections offered by the unions.

A critical experiment construction permit has been awarded by the A.E.C. to Lockheed Aircraft Corporation. The facility will allow two halves of a circular cylinder with a diameter of approximately 12 in. to be brought together by remote control. Interest will centre largely on studies of the critical mass with varying core compositions and the temperature coefficient of reactivity up to 500°C. Beryllium will be the moderator in most experiments.

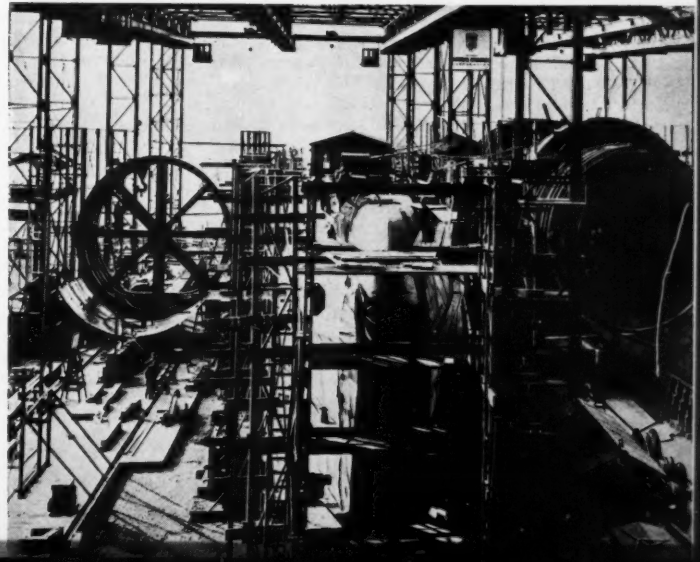
A 1-MW pool-type research reactor has now been licensed by the A.E.C. for shipment to the Land Bayern, Federal Republic of Germany, for erection by A.M.F. Atomics Inc. at the Laboratorium fuer Techniche Physik de Technischen Hochschule Muenchen near Munich.

Boron-10 is to be made available in kilogram quantities by the A.E.C. for non-government uses. Prices for enrichments, varying from 30% to 95%, range from $0.85 to $5.30 per gram for dimethylether boron trifluoride complex, from $1.25 to $5.65 per gram for potassium fluoborate and from $3.10 to $8.60 per gram for boron metal.

Naval contracts to a value totalling over $11¼ million have been awarded for drive units for the nuclear-powered aircraft carrier and for five nuclear-powered submarines. The contracts cover the machinery external to the reactor and have been awarded to Westinghouse and General Electric.



(Left) Checking the control-rod-drive assembly for the 50-kW solution-type research reactor which Atomic International are supplying to Japan Atomic Energy Research Institute.



(Right) Three U.S. nuclear-powered submarines under construction at Groton, Connecticut. L. to r.: Skipjack, Skate and Triton. The U.S. claims that Skipjack will be the fastest submarine ever built and that Triton will be the largest.

Industrial Notes

Bailey Meters and Controls Ltd. announce that their main project and estimating section has now been transferred from their Moorgate address to Purley Way, Croydon, Surrey (telephone CROydon 4191), to which all correspondence should be addressed.

Standard Telephones and Cables Ltd. have opened a cable depot in Nottingham at 33 Pilcher Gate (telephone Nottingham 52333).

Keith Blackman Ltd., of Mill Mead Road, London, N.17, announce that the Blackman Export Co., of 23 Queen Square, London, W.C.1, is now a wholly-owned subsidiary company.

The Stella Lamp Co. Ltd. has now removed its headquarters to 158 Shaftesbury Avenue, London, W.C.2 (telephone COVent Garden 3031).

Honeywell-Brown Ltd. have moved their Middlesbrough branch office to 52-60 Fletcher Street (telephone Middlesbrough 44221/3).

Accles and Pollock Ltd., a T.I. subsidiary, are supplying more than 200 miles of small-bore stainless-steel tubing to the G.E.C. Simon-Carves group for the Scottish station and to A.E.I.-John Thompson Ltd. for Berkeley.

Philips Electrical Ltd. have moved their sales and order departments from Great Queen Street and Century House to their new S.E. Regional headquarters at 1 Gerrard Place, London, W.1 (telephone GERrard 9941).

Chamberlain Industries Ltd. announce the appointment of Electricals Ltd., 14 Claremont Place, Newcastle upon Tyne, 2, as agents in the Westmorland, Durham, Northumberland, Cumberland and Tees-side area for bending machines up to 4 in. capacity.

William Jessop and Sons Ltd., of Brightside Works, Sheffield, are now providing an off-the-shelf service of more than 90,000 high-speed tool bits in 72 standard sizes. Monthly stock lists are issued.

The Pyrene Co. Ltd., of 9 Grosvenor Gardens, London, S.W.1, have provided the CO_2 fire protection for HERMES.

The English Electric Co. Ltd. announces that it has received an order from the Admiralty for the design and manufacture of the main steam turbines and condensers for Britain's first nuclear-powered submarine. This order covers the prototype machinery, which will be tested in a land-based hull, and also the turbines to be installed in the first sea-going submarine.

EDUCATIONAL COURSES

Manchester University is holding a seven-week post-graduate course in nuclear engineering from May 21 to July 5. The course fee is £40 excluding accommodation and meals. Applications should be addressed to Professor Diamond in the Department of Engineering.

The University of Nottingham is planning a residential course in nuclear engineering to be held from September 15 to 21.

Battersea Polytechnic is holding an Easter vacation course in nuclear metallurgy from April 9 to 12. Fee for those outside London or whose local education authority will not assist is £10 10s., otherwise it is £1.

The U.K.A.E.A. is holding a five-day course in radiological protection from April 29 to May 3. Inquiries should be sent to the Isotope School at Harwell.

Enrolment for the one-year post-graduate course in nuclear power at **Imperial College of Science and Technology** will begin in October.

PUBLICATIONS

Aluminium Cable Jointing.—Brochure of cable, lugs, solderless terminals, crimping equipment (including hydraulic crimping units) from Erma Ltd., Hong Kong Works, Exhibition Grounds, Wembley, Middlesex.

Cutting Oils.—A brochure with charts from Amber Oils Ltd., of 11a Albemarle Street, London, W.1, with charts of recommendations for cutting oils on various operations, speeds and materials.

Instrumentation.—No. 4 of the *Evershed News* is devoted to the subject of fuel efficiency and contains articles on automatic combustion control and the Evershed simple computer devoted to fuel efficiency. No. 5 of the same publication includes an article on electrically-operated process control equipment. This periodical is published by Evershed and Vignoles Ltd., of Acton Lane Works, Chiswick, W.4.

Collimators.—New types of collimators for medical use which give an improvement of approximately 4 X in the figure of merit are described in No. 79 of *Tracerlog*, a publication issued by Tracerlab Inc., represented in Great Britain by The Solartron Electronics Group Ltd., of Thames Ditton, Surrey.

Spectrophotometers.—Baird and Tatlock (London) Ltd., of 14 Cross Street, Hatton Garden, London, E.C., have issued a leaflet on Beckman spectrophotometers of various types (including flame analysis and infra-red instruments). This company has been appointed authorized agents in the U.K. for Beckman Instrument Inc.

Parasitic Growths on Tin.—The *Avo News*, Vol. 1, No. 2, includes an interesting article on faults caused by the growth of microscopic whiskers on the tin coating of soldering tags, causing high-resistance short-circuits. The whiskers are quite invisible to the naked eye. *Avo News* is published periodically by The Automatic Coil Winder and Electrical Equipment Co. Ltd., of 92 Vauxhall Bridge Road, London, S.W.1.

Nickel Plating.—The publicity department of the Mond Nickel Co. Ltd., of Thames House, Millbank, London, S.W.1, has issued a 72-page booklet entitled "Nickel Plating for Engineers" which will prove exceedingly useful to designers and engineers who are more concerned with an overall picture of the possibilities of plating and the available methods rather than the minutiae of plating techniques. Nevertheless, it could well claim to be a practical handbook to nickel plating, and deals with the subject from surface preparation through alternative plating procedures, practice applications, plant, testing of coatings, heat treatment, etc., concluding with tables of technical data and a list of 27 references to other published work.

"Plant Construction Services" is the title of a brochure issued by Head Wrightson Processes Ltd., of 24 Baltic Street, London, E.C.1, in which they outline their organization and history. There is an illustrated review of a number of major contracts in which the company has played a major part, including several oil refineries and atomic projects, and several pages are devoted to a review of typical units, including cooling towers, heat exchangers, tube stills and pressure vessels.

Mopumps.—Rhodes, Brydon and Youatt Ltd., of Stockport, have sent two new brochures on Mopumps. One is a revised and enlarged edition covering the chemical-process Mopump; the other describes the new, vertical, high-temperature unit. Both are complete with selection charts and dimension tables.

Electronic Apparatus.—A complete binder of leaflets with price lists has been received from Airmec Ltd., of High Wycombe, Bucks.

Feed-water Treatment.—Two new leaflets on Zerox, a 35% Hydrazine solution for the deoxygenation of boiler feed-water, have been issued by Whiffen and Sons Ltd., Fison House, 95 Wigmore Street, London, W.1.

Orbits in Industry

Memories of earlier days were evoked at the reception given at the City and Guilds when the new Sunvic computer was turned over to Imperial College; a reception attended by many notabilities, including the Atomic Admiral, as one fears Admiral Wilson will inevitably be known. The computer, of the analogue variety, is intended for heat-flow problems, and its operation, once set up, is completely automatic over the required series of time cycles being studied.

The memories evoked were of personal association with what is believed to be the very first analogue computer ever constructed in this country and, by a peculiar coincidence, by another A.E.I. company—although at the time A.E.I. was still in the future. More than thirty years ago B.T.H. switchgear specialists at Willesden realized that, although there was not yet a Grid, large-scale interconnection of power systems was inevitable and, equally inevitably, network short-circuit calculations would be getting a bit out of hand for pencil-and-paper solution. They constructed accordingly a simple analogue computer of multiple resistance networks and telephone jacks, promptly dubbed the "Steam Piano" by the lewd and licentious types of the Experimental Test to whose lot fell the simple chore of checking its connections. Looking at the new Sunvic computer, with its deceptively simple and streamlined (horrible but expressive word) appearance, and its electric typewriter chattering angrily away like a P.A.-Reuter ticker, and realizing that it was a direct descendant, even if it did make its ancestor look like a child's abacus, one could not help wondering if, in thirty years' time, it would look as outmoded as the old "Steam Piano" does today.

Brassbound?

The news that the chairmanship of the Nuclear Propulsion Committee would be in Admiralty hands was received with mixed feelings. The Admiralty can perform fantastic feats in wartime and, at any time, it has a large number of brilliant men available. Collectively, however, it is inclined to take its time and to require something better than the best. This will ensure that the design is solid and safe. Whether it will be competitive, however, is another matter.

On the Nod

Diamond merchants in Hatton Garden and members of the Stock Exchange are reputed to do business worth many thousands of pounds with nothing but a mutual nod of understanding, but the biggest deals ever done this way must surely be in our own industry. Owing to some mysterious break-down in a complex system, at least one of the main contractors for the new power stations was well advanced with construction work before he received a single scrap of paper officially notifying him that he had the order. Not, of course, a full-blown contract document covered with parties of the second part, seals and sixpenny stamps—anybody who's ever bought a house knows how long that takes—but one would have expected a simple little note saying in effect, "Dear Sir, We should like to buy one of the power stations shown in your catalogue . . ." or words to that effect. Apparently, everybody thought that someone else had done it. For the sake of the sales manager's ulcers, it's a good job they were dealing with a reputable concern, isn't it? But someone must occasionally have felt rather like the Victorian heroine without her marriage lines.

Reactors and Railways

The esoteric connection between nuclear power and locomotives was one of the topics touched on by Professor J. M. Kay in his inaugural lecture as Professor of Nuclear Power in the Department of Mechanical Engineering, Imperial College. Earlier, in his introduction, Professor O. A. Saunders, Dean of the City and Guilds College, had spoken of the reason for the incorporation of the chair in the faculty of engineering rather than that of science, pointing out that the university regarded nuclear power not as a new branch of engineering but as a new development in many existing branches, mechanical engineering being that most intimately concerned.

Professor Kay's lecture was formally entitled "The Nuclear Power Programme and Its Impact on Education", but its main message really was that, in the nuclear power programme, the Industrial Revolution was repeating itself. In the days of Boulton and Watt, Britain had enjoyed a unique position in the field of power production and engineering generally and had allowed herself to be overtaken by other nations. History had repeated itself and she was now in the same position again. This time the lead must not be lost. Had the late Victorian developments in engineering education been early Victorian, the position of 1851 would have been unassailable.

And the connection with locomotives? Sir Christopher Hinton, whose words Professor Kay quoted at some length, was apprenticed at Swindon. Professor Kay was at Crewe. Simple when you know, isn't it?

Pay As You Save

One of the lighter moments of the lecture, incidentally, was concerned with the financial arrangements of Boulton and Watt, who, as is not always realized, did not sell their engines outright but charged a royalty of one-third of the saving in coal achieved by the use of their engines, for a period of 25 years. Pointing out that Sir Josiah Eccles was in the audience, it was suggested that some of the nuclear power groups might feel inclined to adopt similar schemes of payment. Had this suggestion been taken seriously, the traditional "flutter in financial circles" would, one feels, have been a full-sized flap.

No Friendly Beam . . .

The non-appearance of power from atomic energy at the Philadelphia Congress opening ceremony must have been received with mixed emotions. For coarse-fibred competitors this sort of thing is as good as a week at the seaside, but for those responsible it must have been very unfunny. A hitch at the opening of the local flower show is bad enough, but a hitch at an international exhibition, knowing that news agencies on the other side of the world are tumbling out of bed to pass on the joke, is a great deal worse. One is left, in fact, in the unenviable position of the illusionist at a Command performance who has really sawn the lady in half, and is gloomily wondering whether the coroner will see the joke. Small consolation though it may be, the way of the pioneer is always beset with pitfalls. "Tangent" remembers a comparable incident in the days when radio was about in the stage that nuclear energy is today. It was at the very first "Wireless Exhibition", when there was no regular broadcasting, but 2 L.O. (then Marconi House) had laid on a special transmission for the official opening, and everybody was all agog. Alas, despite the frantic efforts of at least four boffins with a set like DIDO's control panel, nothing emerged but howls and grunts, although the distance was less than a mile.

The more one sees this sort of thing, the more one realizes that the most poignant words in the English language are contained in an early motor-cycling manual, which details the preparation to be undertaken for one's first ride. After describing every move, from the uncrating of the new machine to the final tickling of the carburettor, the chapter concludes with nine words that, for our money, sum up more neatly than anything else ever written the longings, the hopes and fears, the incurable optimism of the human race or, at least, that part of it which is rash enough to dabble on the outskirts of matters scientific. . . . "Upon depressing the kick-starter," runs this simple sentence, "the engine should fire."

"Tangent"

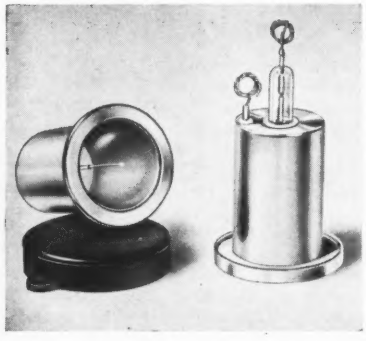
Processes and Equipment

Counter Tube

A mica end-window counter with organic quenching and improved stability has been added to the range of counters made by 20th Century Electronics Ltd., King Henry's Drive, New Addington, Croydon, Surrey.

It has been produced specifically for the assay of samples of low-energy beta-emitters and the measurement of low activity samples. The use of mica end-windows of between 1 and 2.5 mg/cm^2 in thickness permits the efficient use of the counter with beta radiation as low as 60 keV; in addition, the design is such as to reduce background and improve counting stability.

The Type EW2A counter will operate satisfactorily in lead castles made by Ekco, E.R.D. and Labgear and is interchangeable with the CV 2139. For the measurement of very low activity samples, it may be mounted in the anti-coincidence shield consisting of 12 20th Century G24 tubes.



Mica end-window counter introduced by 20th Century Electronics Ltd.

Rigid P.V.C. Fans

A range of centrifugal fans fabricated from rigid P.V.C. is being made by Keith Blackman Ltd., Mill Mead Road, London, N.17, for the chemical industry and other applications where the removal of actively corrosive fumes is necessary.

The fan impeller is a multi-vane centrifugal type with 16 forward-curved blades with shroud and heavy back plate. The steel centre hub is fully protected with a P.V.C. dome and shaft sleeve. The casing of rigid P.V.C. is strengthened by steel base angles and tie bolts painted with Nutracote P.V.C. All other bolts and screws are of stainless steel.

The Series 1 fans have a fume-handling capacity of 50-180 c.f.m. at pressures up to 1.25 in. w.g. They are made with 6-in. and 12-in. impellers and with left- or right-hand bottom horizontal discharge. The Series 2, with impellers from 15 in. to 42 in., have capacities up to 40,000 c.f.m. at pressures up to 4 in. w.g.

Both series are capable of dealing with fumes at temperatures up to 120°F.

Scaler and Pulse Amplifier

A transistorized five-decade portable scaling unit designed for arduous duties in the field or in any situation where compactness and independence of mains supply is essential has been brought out by the nucleonics and electronics department of Dynatron Radio Ltd., The Firs, Castle Hill, Maidenhead, Berks.

The scaler provides a polarizing voltage of 350 to 435, suitable for the halogen-quenched type of G.M. tube. Pulses from the tube are fed to a five-decade scaling circuit of adequate sensitivity and resolving time. This circuit comprises five cold-cathode Dekatron tubes driven by germanium junction transistors. A built-in stopwatch provides automatic timing of a preselected total count of 10^2, 10^3, 10^4 or 10^5 or to monitor a selected counting period.

A test pulse generator is provided, giving fast or slow self-test facilities at the operation of a spring-loaded switch which also controls a battery voltage meter.

The company has also recently introduced a pulse amplifier, Type 1430A. This is a wide-band linear amplifier designed for use with fast ionization chambers, proportional and scintillation counters. The equipment comprises three units: the main amplifier and stabilized power supplies; H.F. head amplifier for ionization chambers and proportional counters; and an alternative cathode follower head for scintillation counters.

The main amplifier has a maximum gain of 86 dB reducing in steps of 2 dB to a gain of 46 dB with an input impedance of 100 ohms. It will deliver output pulses of 50 V positive polarity for not greater than 1% non-linearity. Integrating and differentiating time constants are selected by controls over the ranges of I.T.C. 0.08 μs to 8 μs in seven steps and D.T.C. 0.08 μs to 8 μs in seven steps plus 250 μs step. The H.F. head amplifier has a fixed gain of 31.5 dB and provision for input of either polarity. The cathode follower head unit has an insertion loss of 23 dB and also has provision for input of either polarity. Both these head units incorporate E.H.T. filter circuits.

H.T. and L.T. supplies for the whole equipment are stabilized and the amplifier circuits incorporate negative feed-back, giving a gain stability of the order of 1%.

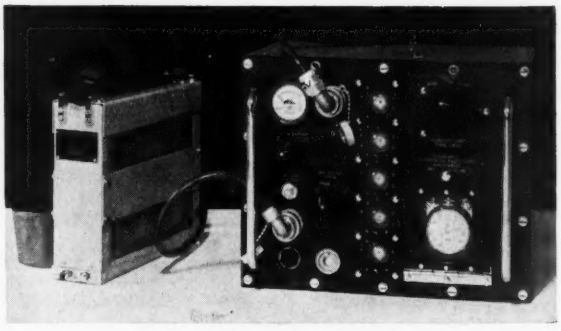
Corrosion-resistant Seal

A mechanical seal has been developed by Crane Packing Ltd., Slough, Bucks, for corrosive service applications. The main seal member is a bellows of pure Fluon to which running faces of glass-reinforced Fluon are welded. Contact between the seal faces and the seats is maintained by a Fluon-sleeved spring. The Fluoseal can be used with all concentrations of acids and salts, strong oxidizing or reducing agents, and with organic compounds and salts. It is not recommended, without careful study of the particular application, for strong alkalis, such as caustic solutions of over 50% concentration, acid fluorides, or fluids containing solids in suspension.

The normal pressure range is from 20 in. vacuum to 50 p.s.i. with a temperature range from −40°C to +80°C. The seal may be run dry indefinitely, provided that arrangements are made for heat dissipation. Seals are supplied for ¼-in. to 2-in. diameter shafts and in two models, one for internal and the other for external mounting.

Sodium Iodide Crystals

Fretco Inc., of 406 North Craig Street, Pittsburgh 13, Pa., U.S.A., are now engaged on research and development in scintillation crystal technology. They have recently begun the production of growing and mounting thallium-activated sodium iodide crystals of high spectrometry and survey grades.



Dynatron transistorized five-decade portable scaling unit.

Enriched Nitrogen-15

From America comes news that nitrogen-15, a stable isotope hitherto available enriched to a maximum of 60%, is now being produced with an enrichment of over 95% by Isomet Corporation, Palisades Park, N.J., U.S.A., using a new nitric acid exchange process. The company announce that the following compounds labelled with N 15 are now available: nitric acid, ammonium nitrate (nitrate labelled), potassium nitrate, ammonium nitrate (ammonium radical as well as ammonium and nitrate labelled), ammonium chloride, nitrogen gas and potassium phthalimide.

Liquid Level Control

A new level controller, the Aquatrol, for use with acids, solutions of salts, effluent or any liquid containing a high percentage of water has been developed by Fielden Electronics Ltd., Wythenshawe, Manchester.

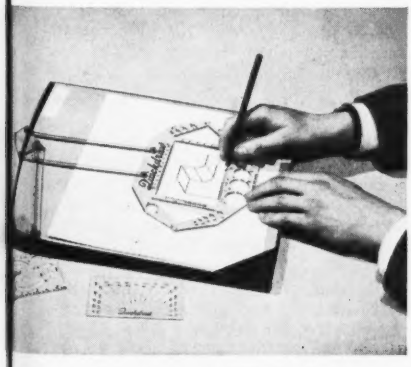
It provides simple, safe and sensitive indication of on-off control of electrically-conducting liquids. Probes, making or breaking contact with the liquid, operate relays which may be connected with warning systems, pump motors or any control function required. It may also be used in pipe-lines as a no-flow alarm.

Drawing Aid

The Quickdraw is a device for aiding the preparation of drawings and sketches with a fair degree of accuracy and to scale.

It consists of a transparent plastics template bevel-edged and carefully formed to produce various angles, triangles and rectangles. It is calibrated in inches and millimetres and the scaling is in $\frac{1}{16}$ in., $\frac{1}{8}$ in. and 1/10 in. Holes in the device allow the drawing of circles from $\frac{1}{8}$ in. to 1 in. in diameter. By placing a ruler against any edge, hatching can be quickly done from a set of nine holes.

The template is toggle-hinged to a strong folder, 14 in. square and $\frac{5}{16}$ in. thick, which acts as a drawing-board. The total weight of the outfit is $2\frac{1}{2}$ lb.



The Quickdraw device for the preparation of drawings and sketches.

Accessories include a stencil cut to give eleven ellipses and two benzene rings, and a methods-symbol stencil.

The makers are the Quickdraw Co. Ltd., 127 Gunnersbury Avenue, London, W.3.

New Aquatrol level controller for use with conducting liquids.

Briefly . . .

Support clips for cables and pipes, made of aluminium covered with Helsyn to make them resistant to most hydraulic fluids, are made by Hellermann Ltd., Tinsley Lane, Crawley, Sussex. There are 31 sizes, accommodating cable bunches from 0.19 in. to $1\frac{1}{4}$ in. diameter.

Prefabricated steel buildings are offered by Sanders and Forster Ltd., Hertford Road, Barking, Essex. Designed on a 10-ft. module, the bay length is 20 ft., with standard spans of 30 ft., 40 ft., 50 ft. and 60 ft. and wall heights of 11 ft., 14 ft., 16 ft. and 20 ft. to eaves. Various claddings are available.

Direct-to-line Class IV push-button contactor starters incorporating a new design of four-pole vertical lift contactor unit, and suitable for use on three-phase supplies at ratings up to $7\frac{1}{2}$ h.p. at 600V, have been introduced by the General Electric Co. Ltd., Kingsway, London, W.C.2. The range will be extended to cover ratings up to 30 h.p.

Hexmetal is a system of fabricated steel honeycomb cells which, when filled with concrete or other binder, forms a reinforced, hard-wearing, crack-resistant flooring or paving. It is being marketed by Causeway Reinforcement Ltd., 66 Victoria Street, London, S.W.1.

Floor-heating cable is now being made by Wandleside Cable Works Ltd., Garratt Lane, London, S.W.18. Florawarm, nylon-sleeved, P.V.C.-insulated cable has a recommended maximum loading per foot run of 5 W, corresponding to a current of 28 amp. at 160°F and 230 V. The standard overall diameter is 0.150 in., but the range will be extended to incorporate other conductor sizes and materials.

A new fire-extinguisher, model PDMU 25, containing 25 lb. of dry chemical powder pressure-discharged by CO_2 gas cartridge, has been developed to deal with fires involving metals such as sodium and calcium, or magnesium and aluminium in powder or swarf form. It is operated by a squeeze-grip control valve. The makers are the Pyrene Co. Ltd., 9 Grosvenor Gardens, London, S.W.1.

A positive-displacement flow-meter suitable for high-viscosity fluids is being made by Brooks Rotameter Co., Lansdale, Pennsylvania, U.S.A. The VAF-Brooks meter is available in sizes from 1 in. to 6 in., up to 450 g.p.m. capacity, and with temperatures up to 660°F and pressures up to 600 p.s.i.

A composite rectifier, the ACR 150, has been introduced by British Oxygen Gases Ltd., Bridgewater House, St. James's, London, S.W.1, for use with their Argonarc welding process. It can be used for welding light-gauge materials, except aluminium and magnesium base alloys, up to $\frac{1}{4}$ in. thick. The current range is 10-150 amp.

Metal sorting and identification of non-ferrous metals and alloys can be carried out with the portable battery-operated Solartron MM611 set. Identification is based on the specific resistivity of the particular metal, provided that it is between 1 and 28 micro-ohms/cm³. It can be used for the inspection of claddings and coatings, variations in hardness, and surface flow detection. It is made by the Solartron Electronic Group Ltd., Thames Ditton, Surrey.

Minireg instruments for voltage, current and watts recording on single phase and watts and varmeter records on three-phase three-wire systems are available with $4\frac{1}{2}$-in. chart giving $4\frac{1}{2}$-hr. visible record with a frontal area of $5\frac{3}{4}$ in. square. Chart drive by synchronous motor or clockwork, and trace by reservoir pen or inkless system on metallized paper. The Stonebridge Electrical Co. Ltd., 6 Queen Anne's Gate, London, S.W.1.

Automatic fan control units for use in paint spray booths and similar circumstances are made by Alfred Bullows and Sons Ltd., Long Street, Walsall, Staffs. The model V1001/2 ensures that the fan is in operation only when the spray gun is in use, thus preventing undue heat losses as well as saving electric power.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 765,239. Leak detection unit. A. Bell. To: Foster Wheeler Ltd.

Points where escape of liquid from a liquid (sodium) containing (heat exchange) system is particularly dangerous can be surrounded with a gas-sealing space to which gas under pressure equal to that of the liquid is supplied. Quick detection of a leak remains, however, imperative. The detector unit at one of the danger points (e.g., a gland) comprises two chambers separated by a membrane. One of the chambers communicates with the sealing-gas space, the other with an indicating instrument. If liquid sodium leaks from the system it contacts the membrane, which will be perforated, and the sodium can then react with the sealing gas to form a smoke of oxide carried to the indicator. As a membrane, Klingerit 1000 is used.

B.P. 765,489. Production of radioactive phosphorus. C. C. Evans, J. Stevenson. To: U.K. Atomic Energy Authority.

Refers to a method of separating radioactive phosphorus from neutron-irradiated sulphur without a solvent extraction step. The phosphorus is subjected to distillation and the residue comprising the phosphorus is taken up with a mineral acid, preferably containing hydrogen peroxide. The sulphur may be distilled in the presence of an inert gas. The condensed sulphur can then again be irradiated to produce a further batch of radio-phosphorus.

B.P. 765,692. Production of beryllium metal. J. Williams and J. W. S. Jones. To: U.K. Atomic Energy Authority.

Beryllium metal produced by electrolysis of a molten electrolyte (beryllium and chloride ions) is refined by comminuting the metal to a particle size of about 10 microns, which is then leached with an aqueous solution of, for example, a polycarboxylic acid or an aromatic compound having one or more hydroxyl groups attached to the ring. After the leaching step, the beryllium is washed with hot water or treated with steam, then annealed in vacua at 500° to 800°C.

B.P. 765,924. Method of separating plutonium. To: U.K. Atomic Energy Authority (Canada).

The plutonium is to be separated from a mixture containing uranium and fission products, including zirconium and niobium. According to an earlier patent, B.P. 754,651 (*Nuclear Engineering*, **1**, 316), this mixture is dissolved in nitric acid, then bismuth nitrate and zirconium nitrate are added as carrier compounds; insoluble phosphates of plutonium, zirconium, bismuth and niobium are precipitated from the solution by adding an aqueous solution of a phosphate. This mixed phosphate precipitate is now subjected to a treatment based on the known fact that bismuth phosphate is easily soluble in dilute hydrochloric acid and on the discovery that, in such dilute hydrochloric acid, plutonium phosphate and niobium phosphate are adsorbed on zirconium phosphate but that plutonium phosphate may be leached from these other phosphates in hydrochloric acid of a strength greater than 7N.

B.P. 766,060. Uranium alloys. E. W. Colbeck. To: U.K. Atomic Energy Authority.

The corrosion resistance of uranium metal can be markedly improved by including in the metal from 0.2% to 10%, preferably 1% to 6%, of its weight of molybdenum. Uranium metal and molybdenum are melted together, in the desired proportions, out of contact with air, under a flux or in vacua in a thoria crucible at 1,150°C to 1,400°C. The alloys may be subjected to an annealing treatment. No substantial competitive neutron absorption is introduced into the uranium metal by the molybdenum.

B.P. 766,061. Uranium alloys. E. W. Colbeck. To: U.K. Atomic Energy Authority.

The alloy includes 0.1% to 5% of its weight of molybdenum and 0.1% to 5% of its weight of silicon. The alloys are prepared as in B.P. 766,060 and may also be annealed in order to relieve stresses. In addition to the higher resistance to corrosion, the tensile strength of these alloys is greater than that of uranium, especially when annealed.

B.P. 766,626. Thermo-setting metal alloys and production thereof. To: Rem-Cru Titanium Inc. (U.S.A.).

The conventional procedure for producing alloys of chemically reactive metals like titanium and zirconium with other metals does not permit the impart ing of intricate shapes; only rough forgings or rolled bar or sheet stock are obtainable. Any desired configuration can, however, be produced at extremely low pressures and temperatures and in precise dimensions in the following manner. A high melting metal (titanium; melting point 1,800°C) is admixed as a fine powder with a powdered low melting metal (tin; melting point 232°C) and the mixture heated to above the melting point of the low melting metal (250° to 300°C). A fluid paste is obtained of the unmelted titanium particles dispersed throughout the plastic tin. At the same temperature (250° to 300°C), the paste is pressed or extruded and then kept at the temperature or raised to higher temperatures (1,200 to 2,000°F) until complete interdiffusion occurs.

B.P. 766,642. Gamma ray detector. To: Texaco Development Corporation (U.S.A.).

In making radioactivity logs of formations in deep boreholes, temperatures exceeding 300°F may be encountered. It has been found that detectors of the electrical pulse-producing, gas-amplification counter type, which have a filling of argon and a small proportion of ammonia as a quenching gas, require additional ammonia at elevated temperatures, as otherwise no correct measurements are obtainable because of insufficient quenching of the counter, probably owing to decomposition of the ammonia constituent into nitrogen and hydrogen increasing with the temperature. By the incorporation of an adsorbent for the ammonia within the sealed envelope for anode and cathode capable of releasing ammonia at the desired temperature, the efficiency of the detector can be increased over a wide range. As adsorbents, silica gel, activated carbon, alumina gel (Al_2O_3) and mixtures of alumina and silica gels are mentioned.

B.P. 766,668. Heat exchangers. N. Davey and W. J. Kramers. To: U.K. Atomic Energy Authority.

A block of sintered ceramic substance (alumina; beryllia; silicon carbide) is provided with groups of passages, one group of parallel passages in one direction, a second group in a direction transverse to the first group. The passages are arranged in layers and headers are connected to the separate groups.

B.P. 766,720. Separation of cobalt and nickel. M. de Merre. To: Soc. Gén. Metallurgique de Hoboken.

A precipitation of cobalt hydroxide from a mixed solution of cobalt and nickel sulphates or chlorides, in certain weight ratios and at a pH of 3 more, by means of nickelic hydroxide. The precipitate is separated and dissolved and then treated so as to precipitate nickel as a cobalt-containing residue obtaining a solution containing cobalt with very little nickel and nickel with very little cobalt. B.P.s 683,679, 650,595 and 655,149 are referred to for the separation of nickel from cobaltiferous solutions by means of Co or Fe.

B.P. 766,726. Device for detecting radiation. To: General Electric Co. (U.S.A.)

Radioactivity is measured on a fluorescent screen by which the radiation is converted into light flashes (plastic scintillation phosphor) which are integrated by a housing with a highly reflecting and diffusing coating (white magnesium carbonate paint). The light flashes impinge on the cathode of a photomultiplier tube connected to indicating and measuring means.